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THIS MONTH'S COVER

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Galvanic Aluminum Anodes For Cathodic Protection★

By R. B. Hoxeng, E. D. Verink,** R. H. Brown****

OVER 100 years ago, Sir Humphrey Davy[1] described the prevention of corrosion by a practice which today is known as cathodic protection. Since that time, theoretical principles of cathodic protection have been formulated and numerous applications have been made.[2,3,4]

According to the electrochemical interpretation, corrosion is a dissolution of metal at the anode of a galvanic cell occurring simultaneously with the passage of an electric curcent between the anode and cathode. The driving force of the corrosion reaction is the difference in the electrolytic potentials of the anodic and cathodic areas. The amount of electric current passed is limited by many factors, such as ohmic resistance of the circuit, and polarization of the anodic and cathodic areas. Numerous causes of potential differences on metal surfaces have been given;[5] sufficient for this discussion is the fact that on underground steel pipelines there are often differences of potential adequate to cause an appreciable flow of electric current resulting in serious corrosion of the structure.

In its simplest explanation, cathodic protection utilizes an applied direct current to polarize cathodic areas of the steel pipe to the potential of the anodic areas of the pipe.[3] The dissolution of metal at the anodic areas then ceases, since there is no driving force for the passage of electric current. A simple method of cathodically protecting a pipeline takes advantage of the fact that certain metals, such as aluminum, magnesium and zinc, are sufficiently anodic to steel that if they are buried and electrically connected to the pipeline, a flow of direct current will be obtained. Metals used in this manner have been termed galvanic anodes, because the flow of current depends on the spontaneous potential developed in the galvanic cell, the electrodes of which are the anodic metal and the steel pipeline.

It is the object of this paper to describe the progress that has been

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made in the development of galvanic aluminum anodes and to present typical service data on their use for the cathodic protection of underground steel structures.

Technical Considerations in the Use of Galvanic Anodes

It is convenient to discuss four technical criteria of galvanic anodes:

1) potential
2) polarization
3) ampere hours per pound of metal
4) stability

It is necessary that the potential of the anode be sufficiently anodic with respect to the potential of the pipeline that electrical current will flow through the ohmic resistances of the circuit. Other things being equal, the greater the potential difference between anode and pipeline, the greater the amount of current obtained from a single anode, but the shorter the life of the anode.

As important as the open-circuit potential of the anode is the amount of its anodic polarization, that is, the decrease in the effective potential of the anode with the flow of current. For convenience in this paper, the term "anode polarization" includes true polarization effects and IR drops at the anode interface and in the backfill. A factor which may be termed the "polarization coefficient" is calculated by dividing the difference in open-circuit and closed-circuit anode potentials by the current. This is commonly referred to as "anode-to-soil resistance." It is very important that anodic polarization or anode-to-soil resistance be low and not increase appreciably with time.* Theoretically it is possible to differentiate between true polarization effects and the IR drops through the ohmic resistances of the circuit[6]; however, such distinctions are not essential for a paper of this scope.

The ampere hour output per pound of metal will be influenced by the compositions of the anode and the backfill and by the operating conditions encountered. The life of a given anode is determined by its weight, the current delivered, and the ampere hours per pound which can be obtained.

The stability of the anode operation with time is of great importance, since it is desirable that a cathodic protection installation operate continuously and insure complete protection of the pipeline over a period of at least ten to fifteen years.

Aluminum Alloys for Galvanic Anodes

Aluminum and aluminum alloys had been associated with the broad field of cathodic protection for several years before their application to the protection of pipelines was considered. In fact, much of the fundamental work on the theory of cathodic protection was worked out with aluminum alloys.[2] As discussed elsewhere,[7,8] cathodic protection is a contributing factor to the corrosion resistance for which Alclad products are so widely recognized. Metallurgically bonded to the core of Alclad materials is a thin layer of metal which is anodic to the core and cathodically protects any exposed portions of it.

During the development of Alclad materials which would be suitable

* Even if the true polarization is not linear, such a calculation affords a qualitative comparison of anode performance. In the case of straight-line polarization, a quantitative evaluation is obtained.

for the variety of conditions in which they are now used, the solution potential relationships of aluminum base alloys were investigated.[9,10] It was discovered that in many solutions aluminum alloys containing small amounts of zinc are anodic to aluminum of commercial purity. Subsequent work has shown that the electrochemical characteristics of certain aluminum base alloys containing zinc make them very suitable for use as galvanic anodes.

Laboratory Tests vs. Service Tests

Although final evaluation of galvanic aluminum anodes must depend on extensive, long-time service, it is felt that laboratory tests play an important role in their development. In designing laboratory tests, it is necessary to determine which features of the application can be duplicated in the laboratory and which cannot. Current and potential measurements which are used for the periodic evaluation of galvanic anodes can be made readily in the laboratory, as can weight-loss measurements for the determination of ampere hours obtained per pound.

In the conventional installation of galvanic anodes, chemicals are mixed with the soil around the anodes to improve their operating characteristics. The quality of anode performance is not only dependent on the nature of the prepared chemical environment known as the "backfill" but also on the composition of the anode. Both of these factors are easily controlled in laboratory tests and their effects investigated. Interference either from other anodes or from stray currents can be avoided in the laboratory tests and certain variables can be isolated more readily than in service tests.

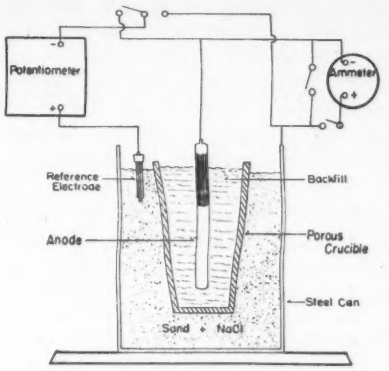


FIGURE 1

SCHEMATIC DRAWING OF LABORATORY ARRANGEMENT FOR INVESTIGATING GALVANIC ANODES

Some factors not readily investigated in the laboratory are: climatic conditions, variable soil conditions, long time anode operation, etc. It is apparent that laboratory tests cannot take the place of service tests. They may serve as a very important supplement, however, determining which combinations of alloy composition and backfill composition are most worthy of testing under actual service conditions.

Laboratory Procedure

In the laboratory, time-performance tests have been utilized in which the anodes have been coupled to steel cathodes and permitted to operate freely. In Figure 1 is shown schematically the laboratory arrangement used for the study of galvanic anodes in wet backfills.

Rods one-half inch in diameter are used as anodes and steel cans approximately six inches in diameter and seven inches high serve as cathodes. A fire-clay crucible is used as a porous diaphragm to prevent the

wet backfill from coming in contact with the cathode surface. In this way, the backfill composition can be varied without affecting the polarization characteristics of the steel cathode. No such diaphragm is necessary when using the packaged anodes, discussed below.

On the outside of the fire-clay crucible, sand saturated with a one normal solution of sodium chloride is used. In order to promote uniformity of current distribution, the bottom of the can is coated with a vinylite type resin, thereby limiting the cathodic area to approximately 120 square inches. The exposed anodic area is limited to approximately four square inches. With this ratio of anodic to cathodic areas, current densities approximating service conditions are obtained on the anode.

During the tests several electrical measurements are made daily, including the short-circuit current, the closed-circuit potential, and the open-circuit potential of both anode and cathode.

This type of experiment furnishes information as to how the open-circuit potential and the anode-to-soil resistance change with time. From the initial and final weight measurements of the anode and from the time-current data it is possible to calculate the ampere hours per pound obtained from the anode during test.

Development of Wet Backfills

Tests with buried aluminum anodes indicated that in order to reduce the inherent tendency of aluminum to form insulating, protective films it was necessary to use chemically treated backfills around the anodes. The more common method of using such anode backfills is to prepare a slurry of the soil and necessary chemicals, pour this slurry into an augered hole, and place the anode in it. In this paper such backfills have been designated as "wet backfills" to differentiate them from "packaged backfills," which are discussed below.

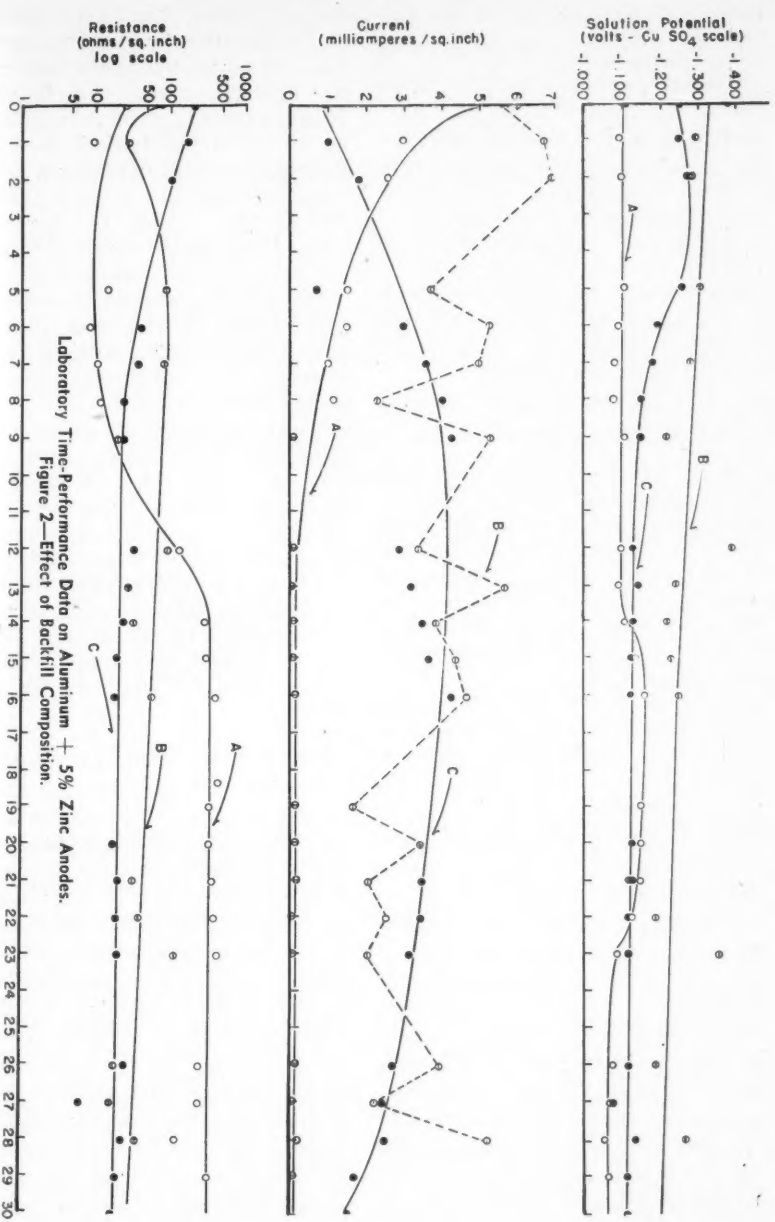
Addition of Alkaline Material to Wet Backfills Beneficial

Early investigations indicated that the addition of an alkaline material such as lime and a salt such as sodium chloride to wet backfills was beneficial. The addition of lime increases the pH of the backfill. This has two desirable effects on the performance of galvanic aluminum anodes; first, the potentials are usually more anodic in alkali and alkaline earth metal hydroxide solutions than in neutral solutions; and second, the products formed around the anodes either have a relatively high solubility or are less adherent in such solutions.

The addition of chloride ions was found to reduce the electrical resistance not only of the backfill but also of the films immediately adjacent to the metal surface. Therefore, the anodic polarization tendencies of aluminum alloys are decreased by the use of chloride ions, resulting in lower anode-to-soil resistances.

Data from typical laboratory tests employing anodes of an aluminum alloy containing five percent zinc are plotted in Figure 2. Hereafter in this paper this alloy will be referred to as "aluminum-5 zinc" alloy. The open-circuit potential, the current, and the anode-to-soil resistance are shown with respect to time.

The difference between open-circuit and closed-circuit anode po-



Laboratory Time-Performance Data on Aluminum + 5% Zinc Anodes.
Figure 2—Effect of Backfill Composition.

tentials divided by the current density, $\left(\frac{\text{mv}}{\text{ma/sq. in.}}\right)$, is the anode-to-soil resistance per unit area. The curves marked "A" represent the results obtained in a lime-salt backfill. The open-circuit potential remained relatively steady, however, the anode-to-soil resistance increased with time resulting in a marked decrease in current. In laboratory tests, aluminum-5 zinc anodes in lime-salt backfills gave from 430 to 550 with an overall laboratory average of 480 ampere hours per pound.

Improvement Obtained by Addition Of Mercury Salts to Backfill

A further improvement was obtained by the addition of mercury salts, such as calomel, to the backfill. Tests indicated that the calomel could take the place of the lime and would give less anodic polarization but could also be used with other backfills or materials surrounding the anodes.

In Figure 2, the time performance curves marked "B" identify data obtained from an aluminum-5 zinc anode in salt-calomel backfill. These data show an increased current which is attributed to lower anode-to-soil resistance and to a higher anode potential.

The tendency for the anode-to-soil resistance to decrease with time in the salt-calomel backfill is of definite significance. In laboratory tests, aluminum-5 zinc anodes in salt-calomel backfills gave from 375 to 650 with an overall laboratory average of 515 ampere hours per pound.

Laboratory tests also showed that by the addition of calomel to the lime-salt backfill further advantages were achieved. The curves marked "C" in Figure 2 typify laboratory results on aluminum-5 zinc anodes in the lime-salt-calomel wet backfills. It is apparent that the potentials are as anodic in this backfill as in the lime-salt backfill, though not as anodic as in the salt-calomel backfill. The anode-to-soil resistance remained low, again resulting in higher current than from lime-salt backfills. The marked advantage of the lime-salt-calomel backfill was the fact that from 540 to 960 with an overall average of 710 ampere hours per pound were obtained.

Final evaluation of galvanic anodes must depend on extensive service tests. Such tests are of longer duration, therefore, the evaluation of anodes under actual operating conditions must necessarily lag behind laboratory developments. It is desirable at this point to consider service tests on aluminum anodes in wet backfills and compare the results with those obtained in the laboratory.

Service Tests With Wet Backfills

Plotted in Figure 3 are data obtained from aluminum anodes in lime-salt wet backfills under actual operating conditions. The anodes for which data are plotted were installed in identical backfills composed of soil containing lime and salt and were coupled to the same steel pipe for 446 days. In addition to checking laboratory tests, these data also serve to compare the performance of aluminum anodes of three different compositions, aluminum containing one, five, and ten percent zinc. It is apparent from Figure 3 that the open-circuit potential of the an-

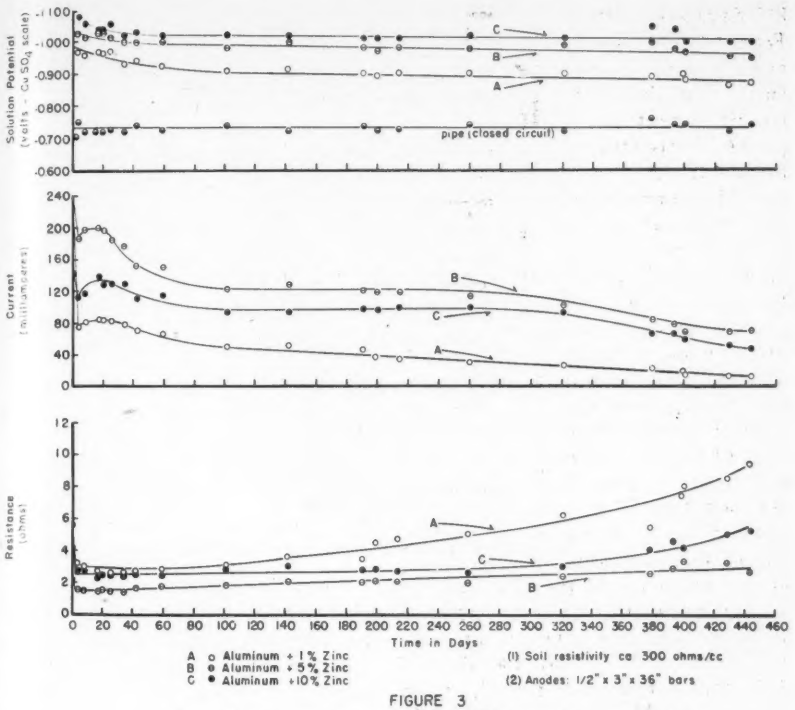


FIGURE 3

SERVICE[1] DATA ON ALUMINUM ANODES[2] IN LIME-SALT-WET BACKFILL
EFFECT OF ALLOY COMPOSITION

odes were higher in the order of increasing zinc content; however, the anode-to-soil resistances of the anodes containing five and ten percent zinc were lower than of the one percent zinc alloy. In view of the generally superior performance, the aluminum-5 zinc alloy was selected as the tentative alloy for galvanic anodes. In service tests, aluminum-5 zinc anodes in lime-salt wet backfills gave from 390 to 600 with an overall average of 510 ampere hours per pound. This is in reasonable agreement with laboratory results. Aluminum-1 zinc anodes in lime-salt wet backfills were more varied, ranging from 445 to 1000 with an overall average of 735 ampere hours per pound. The aluminum-10 zinc anode, tested under the same conditions of service, operated at 405 ampere hours per pound.

To obtain long-time service data, two aluminum-5 zinc anodes were installed in salt-calomel wet backfills, one coupled to a pipe having a pipe-to-soil potential of about 1.0 volt and the other to a pipe having a potential between 0.7 and 0.8 volt. In Figure 4, the measurements made on these two anodes over a period of

250 days are plotted. Figure 4 reveals several pertinent results: first, the open-circuit potential remained fairly steady, at about 1.1 volts; second, the anode-to-soil resistance remained low for both anodes; and third, the anode-to-soil resistance was very nearly equal for both anodes, even though one anode was delivering much more current than the other by virtue of the fact that it was coupled to a more cathodic pipe. This agreement in anode-to-soil resistance is excellent evidence for straight-line polarization. The anodes in salt-calomel backfills operated at 430 and 485 ampere hours per pound, which is in reasonable agreement with laboratory results.

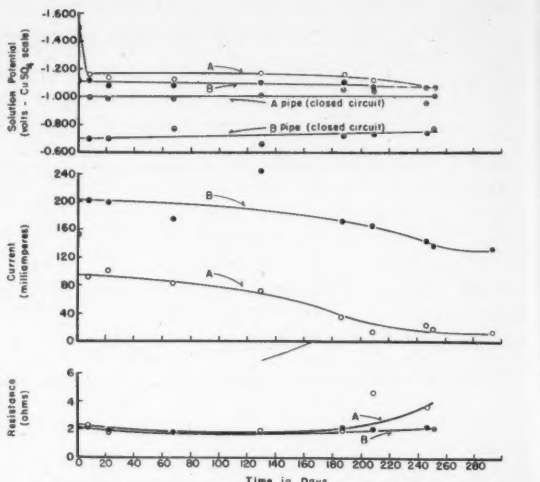


FIGURE 4

SERVICE[1] DATA ON ALUMINUM + 5% ZINC ANODES[2] IN SALT-CALOMEL-WET BACKFILL

TABLE 1

Performance of Aluminum + 5 Percent Zinc Anodes* in Lime-Salt-Calomel Wet Backfills Alluvial Soil, New Orleans—Resistivity ca. 1000 ohms/cc.

TIME	ANODE No. 1 P/S† Volts	ANODE No. 1 A/S‡ Volts	ANODE No. 1 I ma
Initial	0.74	1.19	115
60 Days	0.730	1.10	117

TIME	ANODE No. 3 P/S† Volts	ANODE No. 3 A/S‡ Volts	ANODE No. 3 I ma
Initial	0.70	1.21	120
60 Days	0.725	1.11	130

* Cast anodes 4-7/16" diameter x 21" long weighing about 30 pounds.
† Pipe-to-Soil potential.
‡ Anode-to-Soil potential.

No service tests have been completed using the lime-salt-calomel backfill. Tests now in progress with aluminum-5 zinc anodes in this backfill show that appreciably higher currents are being obtained than from anodes in lime-salt backfills, which is in agreement with laboratory findings. This is evidenced by the data in Table 1 giving the results of anodes now in test in alluvial soil in the New Orleans area. It is expected that at least 675 ampere hours per pound will be obtained on the basis of laboratory tests.

Development of Packaged Backfills

Considerable attention has been given to the development of a packaged galvanic aluminum anode. (Figure 5.) Packaged anodes consist of the usual metal anodes encased in mortar-like or concrete-like materials which contain the necessary

Figure 5—Bare and packaged galvanic aluminum anodes.

chemicals to assure the desired anode performance.

The use of packaged anodes offers several definite advantages:

1) Assures uniform backfill
2) Assures backfill of proper composition
3) Reduces technical supervision required at installation site
4) Avoids wastage of materials
5) Permits anode installations in swamps or marshy ground
6) Reduces installation time
7) Permits the use of production equipment

Assuming the performance of packaged anodes is equivalent to that of anodes in wet backfills, it is obvious that substantial savings, es-

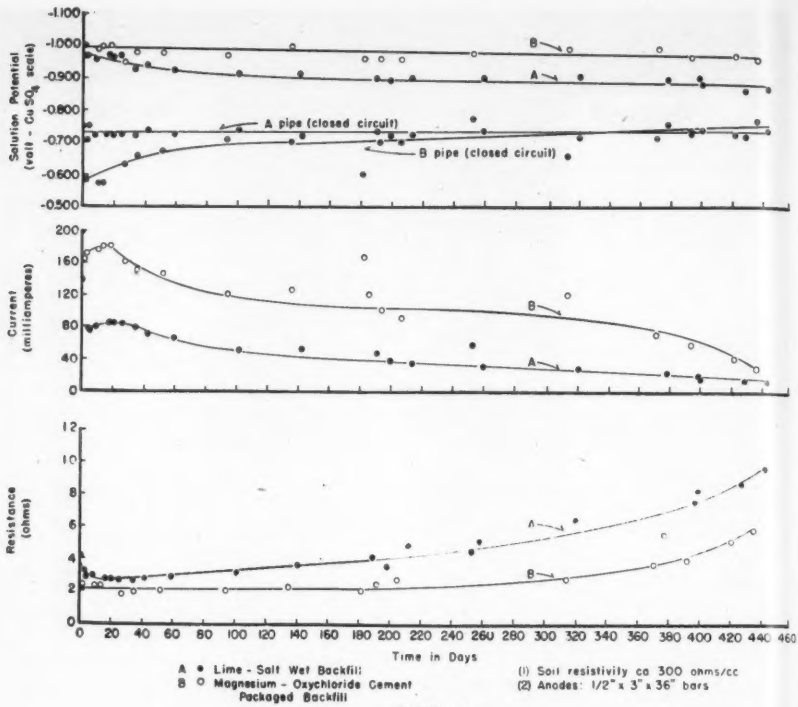


FIGURE 6

SERVICE[1] DATA ON ALUMINUM + 1% ZINC ANODES[2] IN WET AND PACKAGED BACKFILLS

pecially with regard to installation cost, can be had by their use.

Early laboratory tests indicated that aluminum-5 zinc anodes packaged in magnesium oxychloride (Sorel) cement gave about the same performance as anodes in lime-salt wet backfills. In both cases an average of about 480 ampere hours per pound was obtained.

The addition of mercury salts to packaged backfills has given markedly improved results. Aluminum-5 zinc anodes packaged in magnesium oxychloride cement containing calomel gave from 630 to 810 with an overall average of 720 ampere hours per pound. This is of the same order of magnitude as was obtained in the best wet backfills.

As in the development of wet backfills, the results of completed preliminary service tests with packaged anodes are felt to be of definite significance. When the first packaged galvanic aluminum anodes were placed in service, no comparative data were available on the effect of zinc composition, and aluminum-1 zinc bars were used. Two packaged anodes were prepared with magnesium oxychloride cement and two with lime, magnesium chloride, and sand. Shown in Figure 6 are data

illustrating the superiority of an aluminum-1 zinc anode packaged in magnesium oxychloride cement over an aluminum-1 zinc anode in a lime-salt wet backfill. The following advantages are apparent:

1) Higher open-circuit potential
2) Lower anode-to-soil resistance
3) Improved stability

The two aluminum-1 zinc anodes packaged in magnesium oxychloride cement gave 825 and 1050 ampere hours per pound as compared to an average of 735 for aluminum-1 zinc anodes in lime-salt wet backfills under similar conditions of service.

The results obtained from aluminum-1 zinc anodes packaged with lime, magnesium chloride, and sand were definitely superior to the results obtained with wet backfills, although not quite as good as those obtained from anodes packaged in magnesium oxychloride cement. They operated at 595 and 650 ampere hours per pound.

One aluminum-5 zinc anode packaged in magnesium oxychloride cement containing calomel was removed from test after 287 days. Weight-loss measurements showed that it had operated at 635 ampere hours per pound, a marked improvement over aluminum-5 zinc anodes in either lime-salt or salt-calomel wet backfills. Extensive service tests are now in progress more completely evaluating the performances of aluminum-5 zinc anodes packaged in magnesium oxychloride cement containing calomel. Table 2 gives data from anodes now in test in an alluvial soil having a resistance of about 1000 ohms/cc.

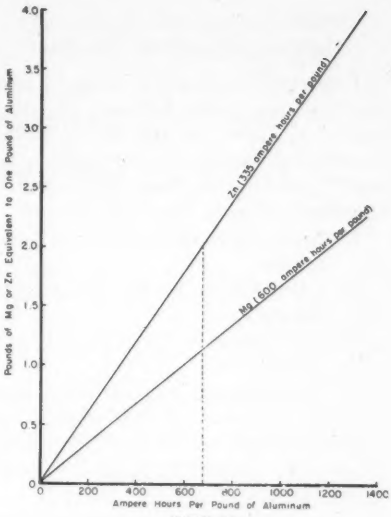


FIGURE 7

WEIGHTS OF AL, MG, OR ZN FOR EQUIVALENT AMOUNT OF ELECTRICITY

TABLE 2

Performance of Aluminum + 5 Percent Zinc Anodes* in Magnesium Oxychloride Cement Packages Containing Calomel Alluvial Soil, New Orleans — Resistivity ca. 1000 ohms/cc.

TIME	ANODE No. 2 P/S† Volts	ANODE No. 2 A/S‡ Volts	ANODE No. 2 I ma
Initial	0.60	1.04	5.0
60 Days	0.705	1.08	90
TIME	**ANODE No. 4 P/S† Volts**	**ANODE No. 4 A/S‡ Volts**	**ANODE No. 4 I ma**
Initial	0.60	1.00	0.5
60 Days	0.718	1.09	110

*Cast anodes 4-7/16" diameter x 21" long, weight about 30 pounds, encased in package 8" diameter x about 28" long.
† Pipe-to-Soil potential.
‡ Anode-to-Soil potential.

TABLE III

Relative Metal Cost Per Ampere Year

METAL	Ampere Hours per Pound Estimated	Pounds of Metal per Ampere Year	Price Factor*
Aluminum	675	13.0	1.00
Magnesium	600	14.7	1.62
Zinc	335	26.2	1.81

* Based on currently quoted anode prices in carload lots.

Present Economic Status of Galvanic Aluminum Anodes

From the foregoing laboratory and service data it can be seen that the technical development of galvanic aluminum anodes in wet and packaged backfills has been successfully directed towards:

1) Increasing anode-to-soil potential
2) Decreasing anode-to-soil resistance
3) Increasing ampere hours per pound

At the present stage of development it is believed that aluminum anodes will give at least 675 ampere hours per pound in properly prepared packaged or wet backfills.

Figure 7 is a graph showing the pounds of aluminum, magnesium or zinc required to provide equivalent amounts of electricity. Aluminum at various ampere hours per pound is compared with magnesium and zinc at their presently accepted optimum values. At 675 ampere hours per pound, one pound of aluminum does the work of 1.12 pounds of magnesium or two pounds of zinc.

Table III compares the relative metal cost per ampere year for three metals based on currently quoted anode prices. On this basis, it is apparent that light metals can supply current more economically than zinc. Obviously, in addition to metal cost, the installation costs must be included in determining the total cost per ampere year. By using packaged anodes, substantially reduced installation costs are anticipated.

Development work now in hand gives promise of more ampere hours per pound and of improved packaging techniques, hence it is not unreasonable to expect further improvement in cathodic protection by using galvanic aluminum anodes.

Many of the developments described in this paper are the subject of patent applications owned by the Aluminum Company of America.

Acknowledgments

For making available the data reported on galvanic aluminum anodes under actual service conditions, the authors wish to gratefully acknowledge the assistance and cooperation of Messrs. C. L. Morgan and H. M. Fanett of the United Gas Corporation, Houston, Texas, Mr. S. E. Trouard of the New Orleans Public Service, Inc., New Orleans, Louisiana, and Mr. R. J. Kuhn, Consultant Engineer, New Orleans, Louisiana.

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Corrosion and Preventive Methods In the Katy Field*

By R. C. Buchan
Humble Oil & Refining Company, Houston, Texas

CORROSION of equipment used in producing condensate reservoirs is becoming an old problem in the industry. Most of the present knowledge pertaining to the subject has been well summarized in the form of tentative conclusions in a recent API paper.[1] Intensive efforts are being continued on this problem by committees under the sponsorship of the American Petroleum Institute (API), Natural Gasoline Association of America (NGAA), and the National Association of Corrosion Engineers (NACE). Additional work is being done by the U. S. Bureau of Mines, and by the research and operating departments of the producing companies.

It is the purpose of this paper to present the specific problem encountered in one of the larger condensate fields, and to discuss the problem essentially from an operating viewpoint.

Long periods of research are in prospect. Because of the numerous unevaluated and possibly some unrecognized variables connected with the problem, and because of the apparent inconsistency of the observed phenomena, a major effort should be directed toward full-scale field experiments. This is being done in the Katy Field; and, although all corrosion is not under control, a reasonably early solution of the problem in that field appears likely.

The Katy gas-condensate field, located in Waller, Harris, and Fort Bend counties about 30 miles west of Houston, Texas, is an oblong domal structure covering an area of approximately 30,000 acres. The average well depth is 7600 feet. The formation between 6250 feet and 7450 feet below sea level is divided into six separate sand reservoirs—each of which consists of one or more lenticular members. The porosity of the sands varies from 18 to 35 percent. Each reservoir has a definite water table, and producing wells are completed well above the gas-water contact.

The field was discovered in 1935, and developed rather slowly. A cycling plant was put into operation in January 1943, and an absorption plant was added later that year. The entire field was utilized, and the plant enlarged in 1944. The present

*A paper presented to Division of Production, at the API meeting, in Chicago, Ill., Nov. 13, 1946.

major facilities in the field consist of: 33 producing wells; 36 miles of gathering lines; an absorption-compressor plant; 34 miles of injection lines; and 13 injection wells. Almost all of the equipment and materials selected are those suitable for working pressures encountered in a non-corrosive, non-abrasive service.

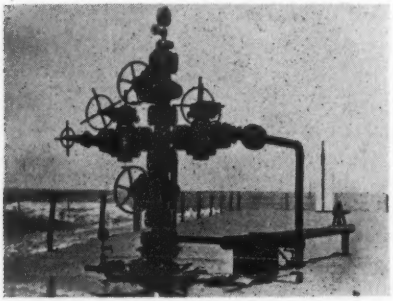

Figure 1—Well-head assembly on a producing well.

The producing wells were initially completed with either 7-inch or 5½-inch OD oil-string casing and with 2½-inch or 2-inch tubing, set without packers so that wells could be produced from both the casing and tubing. Surface casing, 10¾-inch or 9⅝-inch OD, was set at a depth of at least 3500 feet in all wells. Producing wells were equipped with 6000-psi test well-head assemblies, which included adjustable chokes with 1-inch ID beans on the tubing and casing outlets. Injection wells are equipped with tubing and with 10,000-psi test well-head assemblies. Figures 1 and 2 illustrate typical well-head assemblies.

The gathering system is of welded construction, and consists of nine main lines into which the individual well lines are connected, usually at right angles. The pipe size varies from 4 inches to 10 inches, but most of it is 8 inches. Lines were tested to at least 3100 psi with water, after installation. The pipe sizes in the injection system vary from 4 inches to 12 inches, and were tested to 4100 psi. No lines were doped or wrapped. Cathodic protection is not used except in the plant area, to protect lines in the plant.

The absorption-compressor plant was designed for an absorber pressure of 1800 psi. The actual pressure used varies between 1800 psi and 1850 psi, and the lean gas is compressed to 3150 psi for injection.

Six-inch lines and meters are used at injection wells, and these are connected to 3-inch or 4-inch well-head fittings.

Operation of the Field

Until January 1943, wells remained shut in, or were produced at low rates—mainly for fuel for drilling operations. From January 1943 to April 1946, wells were produced at fairly high rates through the casing and tubing. During this period, the flowing well-head pressures

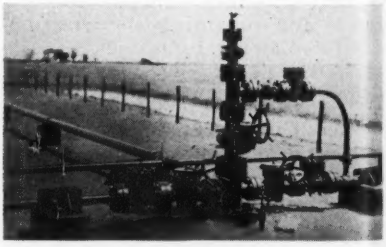

Figure 2—Well-head assembly on an injection well.

were between 2400 psi and 2630 psi; producing rates were 2 to 36 million cubic feet per well per day (most were between 20 and 25 million cubic feet); and the well-head tem-

peratures were between 144 and 180° F. (most were between 170 and 175° F.).

During April 1946, all production through the casing was discontinued and work was accelerated to replace some of the corroded 2-inch and 2½-inch tubing with larger diameter tubing, in order to obtain the desired flow capacities without having to reduce the absorber pressure at the plant. Most of the new tubing installed was 4½-inch OD (4-inch ID) or 4-inch OD (3½-inch ID), externally upset with an insert joint to form an internally flush bore. The present flowing well-head pressures are between 2100 psi and 2250 psi; producing rates are 7 to 32 million cubic feet per well per day (most are between 10 and 15 million cubic feet; and the well-head temperatures are between 148 and 170° F. (most are between 150 and 160° F.).

The inlet pressure at the plant varies between 2000 psi and 2100 psi. The temperature of the gas entering the plant varies between 130 and 140° F.

The gas is injected at a well-head pressure of about 3025 psi, and at rates of 7 to 61 million cubic feet per well per day (most wells take 20 to 30 million cubic feet per day). The well-head temperatures at injection wells vary from 100 to 155° F. and average 145° F. The average temperature of gas leaving the plant is 160° F.

Equipment Affected by Corrosion

Corrosion affects to some extent all casing and tubing strings subjected to well fluids. The ferrous surface equipment, including well-head assemblies, meter runs, and the gathering system, are corroding internally. Corrosion in the plant has been negligible; and, although conditions warrant periodic inspections, corrosion is a minor problem there at present, and it is believed that it will not become serious. The casing is believed to be corroding externally as a result of battery currents between the casing and flow lines.

Corrosion Destroys 75 Percent of Tubing in 3½-Year Period

Corrosion of subsurface equipment is the most expensive part of the overall problem. Analyses of waters produced in 1943 indicated that corrosion was occurring in the wells, but the seriousness was not fully realized. During the past 12 months, 12 strings of tubing were pulled after an average service of 3½ years, and only about 25 percent was in suitable condition to re-install. Grade H-40 and J-55 externally upset, non-normalized API tubing was installed initially. Except for the removal of mill scale, the lower part of the strings has not been attacked by corrosion.

The internal corrosion in the remainder of the strings does not follow any given pattern, except that usually the first two feet of the lower end of each joint corrode more rapidly and more severely than does the upper end or the middle of the joint. Figure 3 shows the result of an internal caliper survey, which reflects the condition of tubing after three years of average Katy service.

Complete inspections of the tubing removed from five wells show that no pitting has occurred in the main body of the pipe to within two feet from the ends in three of the five strings, even though pits have penetrated more than 50 percent of the wall in the upset and upset round-

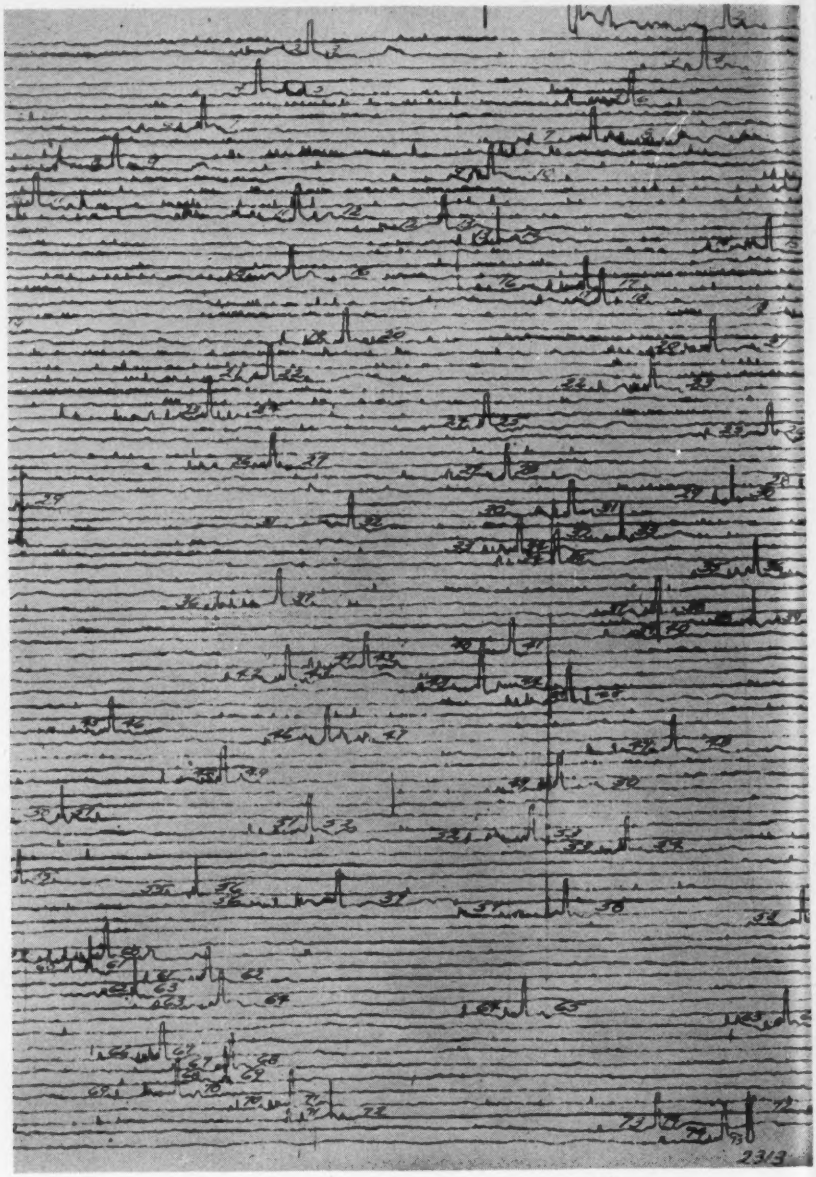

Figure 3—Chart from an internal caliper survey at Katy Field in tubing used three years.

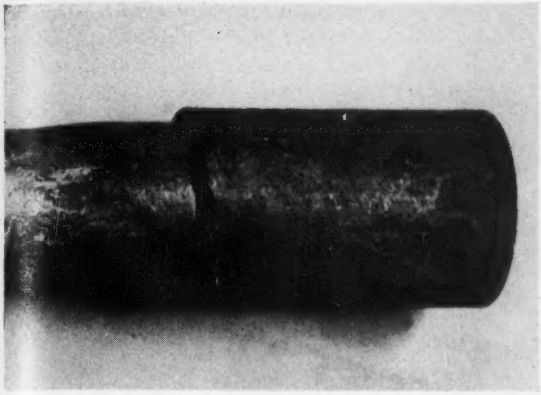

Figure 4—Corroded tubing coupling.

out areas. External corrosion of tubing in wells producing from both casing and tubing has been minor, except that couplings, as shown in Figure 4, are usually pitted—some badly—and the exposed threads are attacked where water can stand. Mill scale appears to be completely removed in less than one year.

Little Is Known Concerning Actual Condition of Tubing

Little is known concerning the actual condition of casing in Katy wells. One string of 5½ inch OD full-length liner was pulled after having been in service 3.7 years. The lower half of this pipe was not visibly affected. Internal corrosion was found in the upper half, and the pitted condition resembled that occuring on the inside of tubing. Most of the pitting was concentrated in an area within 24 inches of the down end of the joint. The top 1200 feet of this string was severely corroded. A number of holes were present in the end of the joints in the threaded section, and approximately one-half inch of the ends of several joints had corroded away as illustrated in Figure 5. No external corrosion was found on this pipe, because it had been set inside of a 9⅝-inch OD string that extends to about 7000 feet. (The external corrosion apparent in Figure 5 was due to atmospheric corrosion subsequent to removal from the well.)

Internal casing corrosion, in the form of pitting, has been found in other wells when well-head equipment changes were made. Figure 6 shows the condition of a piece of casing removed from just below the well head. Suitable tools for determining the extent of internal casing corrosion have not been available. Several recently developed tools will probably be tried at Katy as soon as available.

Almost Every Original Wing Valve Replaced

Corrosion and subsequent leakage made it necessary to replace almost every wing valve installed initially in well heads on producing wells—some after less than two years. The throats and flange facings are most seriously attacked. The design of these valves needs no improvement, but corrosion-resistant materials are needed. Valves lined with several types of stainless steels or with Stellite have given perfect service with no apparent corrosion after more than two years' use. Some of the other alloys used for lining appear

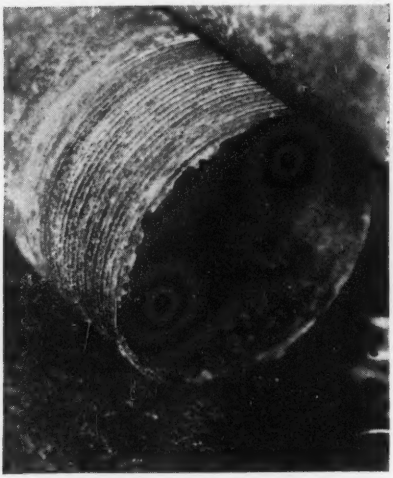

Figure 5—Corroded 5½-inch liner.

to be no more resistant than the ordinarily used steels. The shortage of valves known to be satisfactory in this service has dictated the use of 10,000-psi test valves, to obtain the added corrosion tolerance.

Parts of choke assemblies used on producing wells are frequently replaced. Corrosion and erosion of the stems and beans prevent a tight closure, usually after about 30 days. Stems and beans are replaced every five or six months, because after that time their condition is such that they cease to serve their intended purpose. Hard surfaces, such as are obtained by lining with Stellite and hard electroplated chromium, have been proved to resist this erosion. Because only parts of the surface need protection against erosion, and because such linings are difficult to apply to the entire assembly, the base metal needs to be a corrosion-resistant.

Other parts of well-head assemblies are corroding. Figure 7 illustrates the nature of corrosion on ring-joint flanges. Because of general present lack of any proved material that is not too expensive, the present program includes the use of 10,000-psi test equipment, which provides additional corrosion tolerance. Plastic coatings are being tested in a number of wells; and, although a few of these coatings look promising, the cost of properly coated fittings is about the same as the cost of satisfactory alloys.

Corrosion of Ring Gaskets Serious Problem

One of the more serious problems at Katy, from a safety viewpoint, is corrosion of ring gaskets. Figure 8 shows a ring that had remained in service about two years. Synthetic-rubber "protection" rings are used to keep well fluids from having easy access to the ring gaskets. The rubber rings deteriorate and often disappear in three to four months, and the exposed ring gaskets corrode to an alarming degree in a year or less time. So far, replacements are made as minor leakage indicates failure. Periodic inspections are made, and

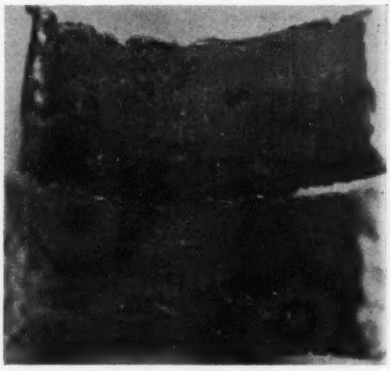

Figure 6—Internal corrosion of casing.

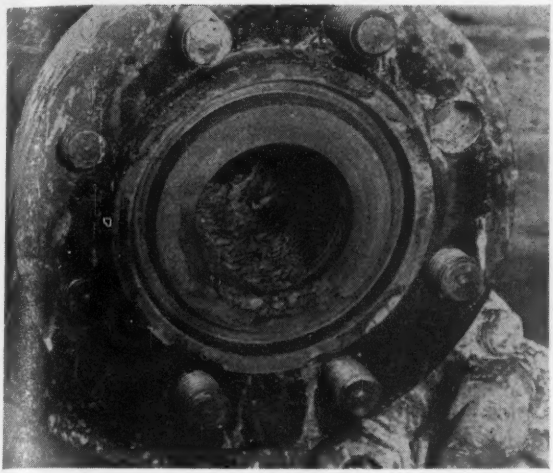

Figure 7—Corroded ring-joint flange.

rings revealing attack are replaced. A search for a better "protection" ring is in effect. Some available plastic materials appear suitable.

Katy is one of the six or seven fields in which a number of alloys are being tested by the NACE Condensate Well-Corrosion Committee. These tests should result in giving the industry a better-selection of materials for combating corrosion in well-head assemblies.

Erosion Aggravates Corrosion at Tie-ins of Well Lines

The corrosion experienced in the gathering system has been confined to the inside bottom of lines, as shown in Figure 9, except that, at tie-ins of individual well lines, erosion has aggravated corrosion, as shown in Figure 10. Some parts of individual well lines have been replaced, and others probably will be replaced within the next year. Heavier pipe is being used for replacements.

Test holes are used as an indication of loss of wall thickness. These holes have been drilled at all points where visual inspections have shown that a tendency toward corrosion exists. The holes are 1/16-inch in diameter, and drilled deep enough that a calculated safety factor of 1.15, based on minimum yield, still exists when corrosion allows the gas to break through the test hole.

Radium inspection of critical locations in lines is also used to a limited extent. This has proved to be a satisfactory, non-destructive spot-inspection method, provided two measurements 90 degrees apart are made at each location so as to detect non-concentric pipe, and provided the individual method is accurate if an unknown amount of liquid is present. No external corrosion is experienced.

Chemicals Minimize Corrosion In Gathering System

Corrosion in the gathering sysem is minimized by the chemicals used to protect subsurface equipment. The reduction in pressure and temperature over that existing a year ago may alter the rate of corrosion. The safety factor for bursting strength has been increased by the reduction of pressure.

No corrosion has as yet been found in the injection lines or injection-well equipment. This is as

would be expected, because the gas contains 50 percent or less water than the amount necessary for saturation entering the average injection wells. One injection well has a well-head temperature of about 100° F., and no corrosion is being experienced — indicating an unsaturated condition at this lower temperature.

The Cause of Corrosion

The internal corrosion of ferrous equipment at Katy is due to the acidic properties of the condensed water under the existing pressure and temperature conditions, as was pointed out by several investigators.[2,3,4] Carbon dioxide and organic acids are present. No doubt other substances are present, some of which probably increase, whereas some decrease, the corrosion rate; but the effect of no single substance has been isolated. The produced gas contains 0.6 to 0.7 percent carbon dioxide. The condensed water at the plant inlet contains 390 to 400 ppm of organic acids (as propionic acid), and about 150 ppm of iron. The pH of the water in the tubing has not been measured because of physical difficulties, but it is believed to be about four.

Search for Answer to Variables Involved

Thorough studies of data from individual wells have not resulted in determining the effect of the several variables involved. The iron content of waters taken at individual wells varies considerably, from 70 to more than 400 ppm. And, in general, the iron content appears to be lower in more wells at high rates of flow than at low rates. All evidence to date indicates that no iron, or not more than a trace of iron, is produced from the formation. Only one well in the field is producing more than a trace of salt water, and it has been under specific observation only a short while. The organic-acid content is fairly constant. No rate of production in any well has eliminated internal corrosion of tubing.

Effects of Erosion

Erosion is minor in the Katy Field in comparison with corrosion. The term erosion, as used in this paper, includes impingement and any cavitational effects. In choke assemblies, erosion and corrosion are equally important, and frequent replacements are required. Plastic coatings are gradually removed by erosion in choke assemblies in one to two months in the average well. Erosion is a problem in only a few spots in the gathering system. The fact that erosion is a minor problem was proved by a study using metal coupons, including one made of 14K gold, and by visual and radium inspections. Erosion does occur in piping at points of abrupt change of direction in the gathering system, particularly where lateral lines connect into main lines at right angles. The localization of corrosion on the inside of API tubing, to near the

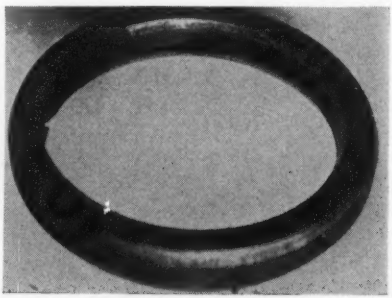

Figure 8—Corroded ring gasket.

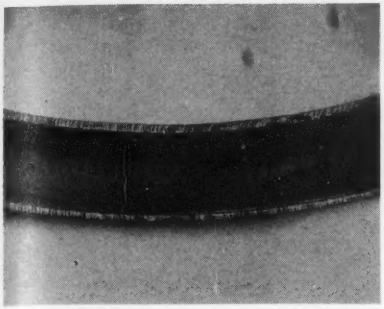

Figure 9—Corroded pipe in gathering system.

down end of the joints could in a sense be connected with erosion; but is thought to be due to a reflux action or an unsteady liquid-film flow, brought about by turbulence at the couplings.

Stray Electric Currents

A rather thorough survey was made of the flow of electric currents in the field. The magnitude and direction of flow in the gathering system was determined, and surveys were made inside of the oil-string casing in a number of wells.

It was found that an average of 1.9 amperes (varied between 0.38 and 3.65 amperes) was flowing into all producing wells, and that an average of 2.9 amperes (varied from 0.89 to 4.96 amperes) was flowing into injection wells. The difference in electric potential was measured between the top of the casing and various points in several wells. This potential varied from 0.0 at the surface to about 30 millivolts at 7000 feet with the flow line connected, and 0.0 to 10 millivolts when disconnected. The current leaves the casing from top to bottom, but a change of slope occurring in the average survey curve indicates that more than the average amount of current leaves at a depth of from 3000 to 3500 feet.

These currents are believed to have no effect on internal corrosion; however, insulating flanges are to be installed to minimize external casing corrosion.

Use of Chemicals to Control Corrosion

Often corrosion can be effectively controlled by chemical means,[5] and this is believed to be true in the case of internal corrosion at Katy. However, at the time that it was decided to try chemical control, conditions in the field made such a procedure undesirable, if not impractical, in many wells—mainly because tubing packers had not been installed. It was believed that the producing capacity of the formation would be reduced by some of the chemicals that might be tried, or by their reaction products.

To make chemical control feasible, it is necessary that: (1) a compound having suitable chemical and physical properties be available; (2) the mechanical arrangement of the equipment be such that chemical can be injected where needed with a minimum amount of trouble and, (3) suitable injecting devices be available.

A research program has been in effect, and is being continued, in a rather intense manner to evaluate chemicals for this purpose. Such work includes the correlation of laboratory-test results with results obtained in field trials. This program has not advanced to a satisfactory solution of the present problem, but it has indicated several approaches toward solution.

Laboratory tests indicated that two chemicals of the inhibitor type,

viz. (1) bone oil; and, (2) carbon disulfide, warranted extensive field trials in wells not equipped with tubing packers. Field trials showed that the bone oil is 50 to 75 percent effective as an inhibitor, but its use had to be condemned because of the odor imparted to the liquid products at the plant. The carbon disulfide was found to be only 15 to 25 percent effective, but it does not seriously affect the product. The low order of effectiveness, and the possibility that the iron-sulfide scale which forms may prove objectionable in time, condemn the use of carbon disulfide. Other inhibitors are to be tested in wells without packers, but it still appears difficult to find a compound that is economical and has no undesirable characteristics.

Soda Ash May Prove Economic Solution to Problem

Laboratory tests and use in other fields indicated that small amounts of neutralizing agents, such as sodium carbonate, sodium hydroxide, and ammonium hydroxide, would effectively reduce corrosion at Katy if properly injected. Soda ash was chosen, because it was easiest and safest to handle, for trial in several wells in which tubing packers were set, and tubing was perforated above the packer to allow egress of the chemical from the annulus to the tubing. After using solutions of soda ash for 90 days in several wells, it is thought that its use may prove to be an economic solution to the corrosion problem at Katy.

Figure 10—Aggravated corrosion at tie-ins in gathering system.

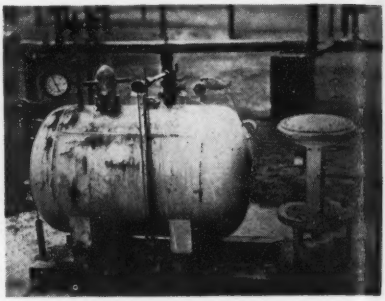

Figure 11—Gas-driven chemical pump.

Eight Wells Presently Being Treated

Corrosion is being controlled with soda ash in eight wells at present (two wells have no packers). One pound of soda ash is dissolved per gallon of water, and is injected continuously into the casing at a rate of one gallon of solution per 1 to 3 million cubic feet of gas per day. The pH of the treated water produced is in the range of 7.0 to 7.8, and it is believed that the pH of the water in the tubing is 6.0 to 6.5. The iron content of the water varies from 10 ppm to a trace, indicating 90 percent or more effectiveness. No operating difficulties have developed as yet from the use of soda ash.

Chemicals useful in one field may not be useful in another. The converse is also true. Chemicals that are applicable in wells producing little or no salt water may have to be discontinued when salt-water production increases.

Any chemical injection in this work should be continuous rather than intermittent, and this has been proved at Katy. Gas-driven chemical injectors of the type commonly used in the oil fields often function erratically when injection pressures are above 2000 psi. Figure 11 illustrates one type of newly designed pump which operates well, but further improvement in these devices appears desirable.

Use of Plastic Coatings to Prevent Corrosion

Four strings of tubing lined with a baked-on plastic coating were installed at Katy during August and September of 1946 as replacements for corroded tubing. Tubing was packed off near the bottom, and mud was left in the annulus. The plastic used is that referred to as the "Type 2" in the following discussion. At the time of writing this paper, these wells had not cleaned themselves completely of drilling mud and water, and the water analyses were considered as not being indicative of lack or presence of corrosion.

The Type 2 coating was tried in well-head and other fittings in the Katy Field. Inspection after five months revealed a new condition, except in choke assemblies, where it was gradually removed by erosion in two to four months.

Previous work in other fields led to the trial of coatings at Katy, and it is briefly summarized herein because of probable interest.

Experiments endeavoring to perfect plastic coatings for oil-well tubing service has been carried on intensively for at least five years, but until about 18 months ago no reasonably acceptable product was marketed. All but a few of the available products were readily condemned by laboratory experiments. Most of the earlier field tests of promising coatings were made in corrosive pumping wells, but in 1945 tubing coated with baked-on, thermo-reacting, and thermo-setting plastics was installed in a number of flowing oil wells.

Seven strings of coated tubing using two different coatings were installed in 11,000-foot oil wells in a Louisiana field, where tubing failed in three to four years due to corrosion. The temperatures, pressures, and corrosive conditions encountered in these wells are similar to the conditions in condensate wells in the Gulf Coast region. Figure 12 shows the condition of coated and of bare tubing in these wells, as reflected by internal caliper surveys. The charts taken in these wells are not entirely comparable because of the difference in the length of time that the tubing was in service, but corrosion of bare tubing in this field begins immediately after production starts, and the Type 1 plastic was known to have begun to fail—by flaking off—after it had been in service only three months. The pitting revealed in the tubing coated with the Type 1 plastic is believed to have started eight to ten months after installation. The survey of the tubing coated with the Type 2 coating reveals no corrosion. Type 2 coating has a phenolformaldehyde base, is baked on at ap-

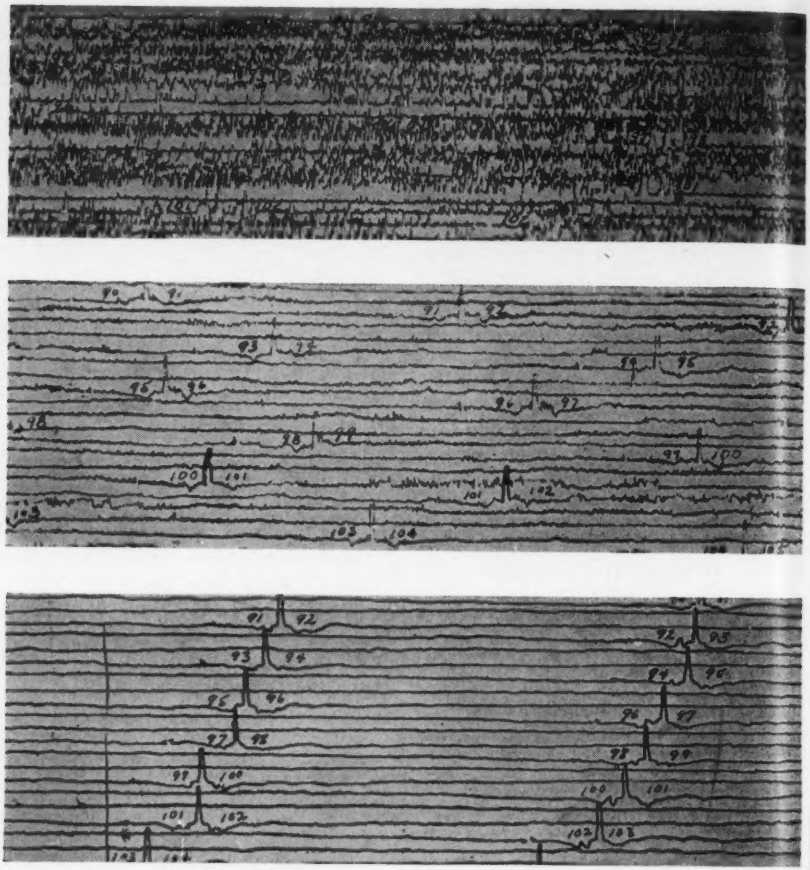

Figure 12—Charts from internal caliper surveys in three oil wells indicating the condition of bare and plastic-coated pipe. Top: bare pipe; center: Type 1 plastic has failed; bottom: Type 2 plastic remains intact.

proximately 350° F, and is applied in several layers, to a total thickness of 0.005 to 0.006 inch.

Experience in the Katy and other fields[5] indicates that operators should expect corrosion in condensate wells having pressures above about 1500 psi, and reservoir temperatures above 160° F., if the gas contains carbon dioxide in excess of 0.2 percent by volume.[6] Previous attempts to classify wells have indicated that possibly 25 to 50 percent of the wells in this class will encounter little or no corrosion. Present indications are that non-corrosive wells in this class are rare, and it is probable that 90 percent are corrosive. In view of this, serious consideration should be given to initially

completing and equipping wells so that control of corrosion is facilitated.

Arrangement of Subsurface Equipment to Facilitate Corrosion Control

At Katy, all of the initial completions consisted of setting tubing, without packers, inside of perforated casing. This conventional method is ideal for obtaining maximum producing capacities from tubing and casing outlets, but corrosion can attack the inside of the casing and both sides of the tubing. Chemical for corrosion control can be injected either into the tubing or casing while production is from the other outlet. Such a control depends on a perfect chemical, i.e., one that has suitable chemical and physical properties, and particularly one that will not lead to plugging of equipment or the producing formation. No highly effective chemical for this purpose has been found. As a safety precaution against otherwise undetected casing leaks, a temperature-survey program is in effect to find leaks if and when they develop.

Some Tubing Reset Large As Casing Size Allows

A number of wells at Katy have been reset with tubing as large as the casing size allows. This permits: first, higher rates of production without large pressure losses; and, second, the injection of chemicals into the casing. A tubing packer is installed near the bottom to prevent chemical from going to the formation. Chemical goes through perforations installed in the tubing just above the packer. With this arrangement, the inside of the casing and the outside of the tubing are subjected to a minimum of corrosion. The principal disadvantage—also true when no tubing packer is used—is that, if the casing leaks due to any cause, a loss of reserves or even a wild well could result.

Tubing packers were used in the four wells that were equipped with steel tubing coated internally with plastic, and the annulus was filled with drilling mud weighing approximately ten pounds per gallon. The economic success of this system, of course, depends on the life of the plastic coating, but almost complete protection against serious casing failures is obtained. If at some later time chemical has to be injected, the tubing can be perforated in place, and injection can be started, or some other means of injecting chemical might be tried.

Consider Installing Two Strings of Pipe Concentrically Inside Casing

Another system that has been considered, but has not been used at Katy, utilizes two strings of pipe installed concentrically inside the oil-string casing, complete with suitable packets. Mud would be left between the casing and the intermediate string, and chemical could be injected either into the innermost or the intermediate string while production is taken from the other. Such settings give the maximum protection against casing failure, but cost more. A rather effective inhibitor is necessary to justify the expense of the two large-diameter strings, if the innermost string is used for the production tubing. If the intermediate string is as large as possible and is used as the produc-

tion string, and if chemical is injected by means of a macaroni string, the hazard of fishing jobs for parted macaroni strings is a disadvantage.

In the foregoing it is assumed that all tubular goods are ferrous material. All types of materials have been considered for tubing service in condensate wells and, with the exception of plastic-coated steel, no material appears to be economical—and this means glass linings, metallic linings and coatings, and alloys having adequate physical and chemical properties. Steel coated with the present semi-proved plastics costs approximately twice as much as uncoated steel. In cases when tubing fails in three to four years, such coatings can be justified if they extend the life of tubing only one year, because the cost of the replaced tubing is usually only 25 to 30 percent of the cost of the work-over. The overall economics involved, insofar as tubing corrosion is concerned, is that a material costing approximately five times that of mild steels can often be justified if it will give trouble-free service for 10 to 12 years.

Economic Aspects of Corrosion Control

The average annual loss due to corrosion in the Katy Field is estimated at $200,000, not considering loss of product, etc. About 75 percent of this is for the periodic replacement of tubing, whereas the remainder is for inspecting and replacing other equipment. This estimate assumes that the casing has not been damaged sufficiently to cause early casing failures. The corrosion losses estimated previously herein would become secondary if one or more wells were to blow out and result in wild wells and loss of reserves. Also, if only a tubing-replacement program is followed in the future, i.e., no corrosion prevention is practiced —the damage resulting from frequent reworking of wells would increase the annual losses by such things as bad luck with fishing jobs, further damage to casing, and possible damage to the formation by mud and water.

Plastic Coatings Deserve Careful Consideration

Though plastic coatings are not a proved product, success to date indicates that they deserve careful consideration. At Katy, for example, all of the tubing in producing wells can be coated for about $140,000, or about the same amount as the estimated average annual workover expense due to tubing corrosion. Should the coating extend the life of tubing only one year, they will pay out in comparison with using bare tubing and no corrosion protection. If plastic coatings will extend the average life of tubing five years, the use of coated pipe will probably prove to be the most satisfactory method of handling the subsurface problem. It would not solve the corrosion problem in entire well-head assemblies because of erosion in choke assemblies, nor does it eliminate the need for probable chemical protection in the gathering system. The best advantage that plastic-coated tubing has to offer is that the tubing can be packed off to obtain protection against casing failures, while a reasonable protection against corrosion is obtained. The monetary value of this safety precaution is

difficult to estimate at the present time.

The successful use to date of soda ash as a neutralizing agent makes it appear to be a practical solution to most of the problems in this field. The relatively small amount of neutralizing agent required could not have been predicted from laboratory tests two years ago. It is estimated that soda ash, when used in all wells, will reduce the average annual corrosion expense in this field to about $50,000. Its principal disadvantages are: first, the need for constant attention and checking; and, second, the fact that either the casing or an additional string of tubing is needed to convey chemical to the lower part of the tubing. The chemical itself will cost about $8000, whereas the remainder is chargeable to: (1) expense of applying; (2) checking results obtained; and, (3) losses not preventable. Some type of chemical treatment appears desirable in the gathering system, and the soda ash injected for subsurface protection also fills this need.

Other more expensive chemicals may prove as economical as soda ash —particularly if they are found and applied in those wells that at present are scheduled for workover jobs so as to postpone or eliminate those workovers.

The amount of future corrosion losses cannot be estimated too accurately because of lack of complete knowledge of the condition of casing in the wells, and because the change in the program of producing only through the tubing will alter the corrosion rate in the tubing, well heads, and gathering system. It is believed that some casing failures will occur in the next few years. This will require the installation of liners in affected wells, and will result in reduced flow capacities. Some additional wells will be required, the cost of which will be chargeable to corrosion. The higher rate of flow through tubing will probably increase tubing corrosion. The lowering of the pressure in the gathering system, amounting to about 325 psi, will probably reduce the corrosion in the well heads and gathering system, so that it will become a minor problem or it will reduce the amount of chemical required to prevent corrosion.

Conclusion

Corrosion encountered at Katy is typical of that found in many condensate fields. Experience in that field will aid in minimizing corrosion losses in other fields.

Two methods of preventing corrosion, viz., (1) use of plastic-coated steel and, (2) use of a neutralizing agent, appear to be useful for reducing the corrosion expense at Katy. The chemicals tried as inhibitors have not been satisfactory. Other chemicals are being tried in individual wells.

Research work has aided materially as a background for full-scale field experiments. Considerably more research is required to obtain a better understanding of phenomena observed in the fields. Continued research is needed to cope with continuously changing conditions in condensate fields and to correlate more closely field tests with laboratory tests.

Continued support should be given to the NACE High-Pressure Well-Corrosion Committee in an effort to

hasten the systematic testing of alloys in condensate-well service.

Operators should expect corrosion in condensate fields and should take corrosion into account when developing new fields or when reworking old fields.

Inspections made early in the life of a field would result in equipping wells so that corrosion control is facilitated, and will reduce corrosion losses. The newer tools—such as caliper surveys and radium inspections—allow rapid, accurate determinations to supplement visual inspections and water analyses.

In fields where corrosion is found, early field trials of promising methods should be made rather than waiting until all of the questions are answered by laboratory studies.

Keeping equipment in a safe operating condition is considered more important than the monetary losses due to corrosion in condensate fields.

Acknowledgment

The author wishes to acknowledge that a large portion of the work done in connection with the problem at Katy was performed by the personnel of the Gas Division and the Production Research Division, Humble Oil & Refining Company. The many pervious papers and reports pertaining to condensate corrosion have been helpful in the preparation of this paper.

The kind permission of the Humble Oil & Refining Company to publish this paper is appreciated.

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Corrosion of Refinery Equipment —A Review★

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CORROSION and the protection against corrosion is an item costing billions of dollars annually, and for the oil industry alone, the cost runs high into the millions.

In the early days of the oil industry the corrosion problem was a simple one but in recent years with the development of the many refinery processes along with the change in the manner of transporting crudes and the different products, corrosion has become a major item. It has become a problem for the chemical engineer and corrosion specialists, who are familiar with the many laws back of the causes. Some of these laws may be chemical in nature, while others may be related to temperature, stress, velocity, abrasiveness of the product, and the like. A few degrees change in temperature one way or the other may affect the corrosion a great deal. With these modern changes, the field is far too vast to attempt to cover it here in this limited space. So only a few of the high points will be covered in this paper; and in so doing, atmospheric corrosion will not be considered.

Selection of Crude

The amount of corrosion in oil refining is fundamentally dependent on the degree of corrosiveness of the crude, which varies over a wide range. By selecting less corrosive crudes, it is possible to reduce the amount of corrosion and hence the cost of corrosion prevention. In our company's crude procurement the corrosiveness of a crude is considered along with a number of other factors in arriving at a decision on its purchase. However, the other factors such as transportation, availability, quantity, and the like oftentimes carry a greater weight and the results are: headaches for the corrosion engineer.

The corrosiveness of crudes is determined largely by five factors, of which the greatest weight, with respect to corrosion alone, is placed on the first three. These are:

1) Hydrochloric acid evolution
2) Hydrogen sulfide sulfur
3) Mercaptan sulfur
4) Total chloride content, reported as sodium chloride, usually referred to as "total salt"
5) Total sulfur content.

The hydrochloric acid evolution is a measure of the acid that will be formed during steam distillation under prescribed conditions. In refinery operation this acid, formed by hydrolysis of calcium and mag-

★ A paper presented at the ASME meeting in Tulsa, Okla., Oct. 7-9, 1946.

nesium chlorides, collects in the condensed steam from crude distillation, forming a solution that is very corrosive to iron and steel, and has been known to corrode through run-down lines in a few months' time when not properly neutralized.

Hydrochloric acid is usually the corrosive medium at temperatures low enough for water to exist as a liquid. There is also some evidence that hydrogen chloride corrosion takes place at higher temperatures.

Before the development of the hydrochloric acid evolution method of analyzing crude by Davis, Jones, and Neilson, attempts were made to determine the calcium and magnesium content of crudes. Such analyses were tedious and our experience has shown them unreliable for determining the extremely small amounts of these substances present in most crudes.

The relative amounts of the three chlorides, taken from an analysis of the deposit from raw Michigan crude (before desalting) in the tubes of a heat exchanger are:

Sodium chloride.....67.83
Calcium chloride.....10.69
Magnesium chloride.. 0.86

With a total chloride content of 100 pounds per 1000 barrels, the magnesium content of crude, representing the principal source of this type of corrosion, approaches the vanishing point. The direct determination of hydrogen chloride evolution gives a good measure of the corrosiveness of the crude in this respect much more easily and reliably than determination of calcium and magnesium.

Hydrogen Sulfide and Mercaptan Sulfur

Hydrogen sulfide and mercaptan sulfur, determined by dry distillation of crude, are of about the same order of corrosiveness, and for convenience can be considered together as "corrosive sulfur" or "distillation sulfur." Corrosion due to these constituents increases with temperature, and is especially noticeable in furnace tubes, cracking unit vessels, and other high-temperature equipment. At high temperatures this form of corrosion is believed to be the controlling factor. Even at lower temperatures non-ferrous alloys, such as red brass and other copper alloys, are attacked by sulfur in this form, but the alloys vary greatly among themselves in rate of sulfur corrosion.

Total Chloride Content (Total Salt)

Before the use of the hydrogen chloride evolution method, the total chloride content was considered an index of the corrosiveness to be expected due to hydrochloric acid formation. Since only calcium and magnesium chlorides, primarily the latter, produce hydrogen chloride in the normal refining operation, the above assumption is not strictly true.

The total chloride content, however, is an important figure, because it is an indication of the tendency of the crude to plug heat-exchanger tubes, and the inorganic solid content of the residual product (coke, heavy fuel oil or asphalt) can be predicted from it.

Total Sulfur

In the case of crudes run in refineries of our company the relation between the total sulfur content and corrosiveness of crude has not been established. However, it is well known that West Texas crude, for example, with a total sulfur content of more than 2 percent is far more

corrosive, at cracking temperatures, than any of our crudes.

Neutralization

Desalting

Desalting is included under this heading, although it has the effect of preventing acid formation, rather than neutralizing it after once formed. Desalting has no measureable effect on the corrosive sulfur content of crude. Desalting equipment has been in successful operation at one of our plants since 1937.

Ammonia

Neutralization of the acidity produced in crude distillation by ammonia is in practice at all of our refineries. Ammonia, being used as a gas, distributes itself well, especially in passage through a fractionating tower, so that no extra equipment is required to give good contact. The amount of injection depends on the materials in the system. If the equipment is of iron or steel construction, an attempt is made to keep the pH between 7.5 and 8.0, and between 6.8 and 7.2 where non-ferrous materials are used.

On one occasion, the raising of the pH from 4.8 to 6.6 on a crude still reduced the iron content of the water from 456 to 45 parts per million. Anhydrous ammonia is purchased in 150-pound cylinders, but consideration has been given to buying it in tank-car quantities. When the required consumption is greater than seven pounds per thousand barrels, there are three serious objections to this form of corrosion prevention, namely:

1) High cost.
2) Plugging of towers, exchangers, and lines, which in some cases have shortened the runs to two weeks.
3) Increased corrosion even with effective neutralization.

In general, ammonia neutralization is of most value in preventing hydrochloric acid corrosion under conditions where water exists as a liquid. Ammonium chloride is stable up to 660° F., whereas ammonium sulfide breaks down at about 110° F.

Solid Alkalies

Solid alkalies are considerably cheaper than ammonia. However, they are not suitable for neutralization of overhead vapors, due to the difficulty of obtaining thorough contacting, and also to the fact that continued contact with alkaline water is damaging to the usual copper-alloy condenser tubes.

Solid alkalies, however, can be of value in preventing acid evolution when mixed with the crude. They can be injected into the crude in measured amounts in the form of a solution, or slurry, and are useful in overcoming the objections to ammonia neutralization alone with particularly corrosive crude.

The three cheapest alkalies are caustic soda, soda ash, and hydrated lime. The first two are readily soluble in water, and can be conveniently used as a solution. Lime is insoluble in water or oil, but can be commonly used as a slurry. The behavior of the three alkalies is quite different. Caustic soda is reported to promote coking in furnace tubes. Lime actually may prevent coking. Soda ash, in our experience, has given no trouble in this respect.

Various kinds of materials have been used in our tubular units, including exchangers, condensers and coolers. The best-suited material for the service is sometimes determined by actual installation of test tubes,

or by the installation of a test spool containing various metals. As a result, our exchanger tubes vary from carbon steel to 18-8 chromium nickel, while condenser and cooler tubes are, generally speaking, admiralty, inhibited to prevent dezincification. Cupro-nickel has also proved quite satisfactory for some special cooler installations.

Where highly corrosive condensing and cooling water prevails there is a definite need for bi-metal tubes, which we hope will be readily available soon at a reasonable cost.

Furnace tubes are usually carbon steel and 4-6 percent chromium 0.5 percent molybdenum. Variations to this statement occur under special conditions, such as low corrosion and high temperature where 2 percent chromium 0.5 percent molybdenum tubes with 1.25 percent silicon are proving to be quite satisfactory. Where the corrosion rate is too high for 2 percent chromium, then 4-6 percent chromium 0.5 percent molybdenum tubes, with 1.25 and 1.50 percent silicon are used for the high temperature operation. The purpose of the silicon is to reduce oxidation, which is accomplished for oil temperatures as high as 1150° F.

In the early days of cracking our radiant furnace tubes were 18-8 chromium-nickel material, but have now been replaced with 4-6 percent chromium-molybdenum, with silicon added where oxidation is a problem.

In cases of localized corrosion, in towers for example, the use of alloys for liners is general practice. These materials include nickel-copper alloys, 11-13 percent chromium and 18-8 chromium-nickel. Some brass lining is done in low temperature crude still distillation. One objection to this form of corrosion prevention is that corrosion often times shifts to another unprotected location hence requiring additional lining.

Where a definite type of corrosion can be anticipated in new installations it is far better to have the lining installed prior to installation as clad, or shop installed spot-welded liners are far better than liners installed in the field.

Cathodic protection, in which the metal that would ordinarily be anodic in a corrosion cell is made cathodic by application of a direct current, has long been used for pipelines and now to some extent in the refinery.

As for non-metallic protective coatings, most of them have temperature limitations in addition to their being not too well suited to refinery operations. However, due to developments during World War II, there are some synthetic coatings that appear as having outstanding possibilities. Some of these are on test in our plants at the present.

In conclusion, it is believed that the best investment a refiner can make today is in corrosion engineers who are familiar with the many problems, and who are capable of solving these problems. With the recent introduction of catalytic refining, the corrosion field has become far wider, requiring the knowledge of chemical engineers as well. The solution is not always easy and often times involves the field of economics to determine the best plan to follow. Never before has the corrosion problem been so complex; and the refiner can justify a considerable expenditure to combat it.

Contributions of Sir Humphry Davy To Cathodic Protection

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SURVEYS of the literature on cathodic protection usually begin with a reference to the work of Sir Humphry Davy. After having cited the customary reference to the literature, the writer proceeds to a consideration of the work of contemporary investigators, with the result that the reader is left to wonder just what contribution Davy could have made in the field of electrical protection 100 years before the electrolytic theory of corrosion became generally accepted, and even before the discovery of Ohm's law and Faraday's laws of electrolysis. Having had occasion recently to read the series of papers[1, 2, 3] which Davy presented before the Royal Society in 1824 and 1825, the writer considered it worth while to prepare a review of Davy's work on cathodic protection for the benefit of those corrosion engineers who, because of lack of time or the unavailability of the early volumes of the Transactions of the Royal Society, are unfamiliar with Davy's contributions in the field of corrosion prevention.

The origin of the principle of cathodic protection is to be found in Davy's early work on the chemical effects associated with the generation of electricity by the original primary battery, known today as the Voltaic pile. In a communication to the Royal Society in 1800, Volta described how he produced an electric current by stacking copper, brass or silver disks alternately with zinc disks, the pairs being separated by an absorbent material, such as cloth, saturated with brine. This discovery aroused the interest of Davy, who showed that in the operation of Volta's battery the zinc electrode was corroded but the other electrode remained unaffected. This and other observations led Davy to the concept of the electrochemical series of the elements.

The rapid failure of the copper sheathing on the hulls of ships of the British Navy provided Davy with the opportunity to apply his discoveries of the galvanic effects of dissimilar metals to the prevention of corrosion electrolytically. In 1823, a committee of the Royal Society was appointed to devise means for preventing the corrosion of the copper sheathing; and Davy was designated to initiate the investigation. The purpose of the sheathing was twofold: first, to protect the wooden hulls from destruction by worms, and secondly a prevent the adhesion of barnacles and other forms of marine life.

Since it was generally supposed

that sea water had little or no action on copper, the corrosion of the copper sheathing was assumed to have resulted from impurities in the metal. However, from the results of a series of chemical analyses made on specimens of copper which had been removed from naval vessels, Davy was able to show in his first report to the Royal Society that the differences in the corrosion observed could not possibly have resulted from impurities in the copper and that the cause of corrosion must be sought elsewhere.

In investigating the nature of the corrosion of copper in sea water, Davy noted an unequal distribution of deposits of green corrosion products, which on analysis were found to be composed of the oxide, basic chloride and carbonate of copper, and magnesium carbonate. Adherence of marine organisms was invariably associated with these deposits. The corrosion observed was attributed by Davy to electrolytic action between the corrosion products and the areas of copper exposed directly to sea water.

"As long as the whole surface of the copper changes or corrodes, no such adhesions can occur; but when this green rust has partially formed, the copper below is protected by it, and there is an unequal action produced, the electrical effect of the oxide, submuriate and carbonate of copper formed being to produce a more rapid corrosion of the parts exposed to sea water, so that the sheets are often found perforated with holes in one part after being used five or six years, and comparatively sound in other parts."

With respect to the fouling which often developed on these layers of corrosion products, Davy remarks: "There is nothing in the poisonous nature of the metal which prevents these adhesions. It is the *solution* by which they are prevented—the wear of surface."

Davy's statement of the problem of preventing the corrosion of the copper sheathing was as follows: "Copper is a metal only weakly positive in the electrochemical scale; and according to my ideas it could only act upon sea water when in a positive state; and, consequently, if it could be rendered slightly negative, the corroding action of the sea water would be null; and whatever might be the differences of the kinds of copper sheathing and their electrical action upon each other, still every effect of chemical action must be prevented, if the whole surface were rendered negative."

The various effects associated with the corrosion and cathodic protection of copper in sea water were demonstrated by Davy in an ingenious manner. A piece of copper wire several feet in length and wound to form a continuous series of coils was connected to a piece of zinc wire one-half inch in length. The zinc and a portion of the copper were placed in one glass and one coil of copper was placed in each of a series of six other glasses and the circuit was completed. The glasses were filled with sea water, and electrolytic conduction was provided by means of thin wicks. After the current had flowed for some time, the copper coil in each glass was examined. In the first glass, which contained both zinc and copper, alkali and alkaline earth carbonates were deposited on the copper coil, except on those parts of the surface which

remained bright, where crystals of sodium carbonate only were deposited. In the second glass, the copper was covered with fine crystals of calcium carbonate, but, as in the first glass, some crystals of sodium carbonate were noted on the bright copper surfaces. In the third glass, all of the copper wire remained clean, the deposited crystals of sodium carbonate being distinguishable only by chemical tests. In the fourth glass, the copper remained bright in consequence of a slight but general corrosion, a scarcely visible deposit of copper salts being noted; in the fifth glass, the deposit of copper salts was clearly visible, and in the seventh glass, the copper wire was completely covered with the corrosion products of copper.

With the assistance of Faraday, who was at that time employed by Davy as a laboratory assistant, a series of laboratory experiments was conducted whereby pieces of zinc and iron were attached to copper in various area ratios and the couples were immersed in sea water. Zinc the size of a pea, or an iron nail prevented corrosion on 40 to 50 square inches of copper.

Encouraged by these results, a similar series of tests was conducted in the harbor at Portsmouth. With an area ratio of zinc to copper of from 1:40 to 1:150 no corrosion of the copper occurred, as demonstrated by weight-loss measurements; but after exposure for four months, deposits formed on the copper coupled to zinc in area ratios less than 1:80. These deposits were found by analysis to be composed chiefly of calcium carbonate, with some magnesium carbonate and magnesium hydroxide. In addition to deposition of these calcareous layers there was considerable fouling by marine organisms. With increase of the zinc-copper ration to 1:150, neither deposition of salts nor fouling occurred, which led Davy to set limits on the degree of protection to be applied, making the "application of a very small quantity of the oxidable metal more advantageous than that of a larger one."

Appreciating the importance of studying the behavior of the zinc-copper couple on ships in the course of an actual voyage, Davy installed on the bow of a ship weighed copper sheets connected to zinc strips so as to provide different area ratios. The conclusion drawn from these tests at the end of the voyage was that the speed of the ship at eight miles per hour did not affect the area of anodic metal required over that determined by simple immersion tests. No deposition of calcareous material or fouling occurred during the voyage.

The practical consequence of Davy's work was that, although corrosion of the copper sheathing could be readily prevented by application of cathodic protection, the problem of fouling was not completely solved. On naval vessels a low rate of corrosion of the copper sheathing could be tolerated providing fouling could be prevented; and Davy was able to maintain a balance between corrosion and fouling by varying the area of the protecting metal. Although fouling on merchant ships could not be entirely prevented, a certain amount of fouling was not objectionable so long as the copper sheathing remained intact. However, as a consequence of the higher speeds of ships which followed the development of steam navigation, the prob-

lem of fouling became less critical.

In connection with the protection of the copper sheathing, Davy had also to consider galvanic effects between the sheathing and the bolts used in the construction of ships. The iron bolts used originally corroded rapidly by galvanic action with the copper sheathing, with the result that ships could not withstand the strains set up in storms.[4] Replacement of the iron bolts with bronze resulted in corrosion of the sheathing immediately surrounding the bolts. To remedy this condition, Davy suggested that the bolts be made of an alloy only slightly more noble than copper.[5] As a matter of interest, it may be noted that a procedure analogous to that recommended by Davy is practiced at least to some extent, to prevent the corrosion of iron bolts used in the mechanical joints in certain present day pipeline systems. By making the bolts of an alloy steel slightly cathodic to iron and steel, it is expected that the bolts will be cathodically protected by corrosion of the surrounding metal.

From this review it is evident that the electrolytic theory of corrosion and certain present-day problems of galvanic corrosion and corrosion prevention were to an extent anticipated by Davy without benefit of electrical theory or even of electrical measuring instruments. Davy's explanation for the corrosion of copper in sea water as being due to an electrical effect associated with local deposits of oxides and chlorides of copper does not differ materially from the modern explanation of the same phenomenon.

The toxicity of copper salts toward marine organisms is today receiving active consideration in the selection of copper alloys for marine use.

As has been previously indicated, the solution suggested by Davy for avoiding galvanic corrosion of bolts in the hulls of ships is the same as that currently advocated for preventing the corrosion of bolts in the mechanical joints of underground piping systems.

With respect to cathodic protection, Davy realized the necessity for control of the current required for corrosion prevention as do modern corrosion engineers. Just as Davy failed to control the cathodically-applied current so as to prevent both corrosion and fouling, so there remain today the unsolved problems of measuring the minimum current required for corrosion prevention and establishing suitable criteria for cathodic protection.

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Discussion of Paper Designing to Prevent Corrosion★

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THE IMPORTANCE of structural design has been discussed with reference to the prevention of galvanic contact and concentration cell effects, which may be the cause of serious weakening of the structure by localized corrosion (or pitting). Ledges or crevices where water and debris may be trapped in contact with the metal should be eliminated in the design as far as practicable. Welded seams can often be substituted for riveted seams. For instance, cracking of steam boilers due to the combined action of concentrated caustic solutions and high localized stresses in riveted seams has been practically eliminated by welding these seams.

Adequate drainage of metal structures exposed in the atmosphere renders the metal more or less self-washing or at least makes cleaning relatively easy.

Most of the failures from corrosion in service are due to local perforation or pitting. The average overall rate of attack uniformly distributed is rarely a matter of concern. For instance, water pipes are frequently pitted through before the weight loss amounts to 5 or 10 percent of the original weight. The intensity of attack on anodic areas increases as the ratio of the anodic to cathodic area decreases. Hence, rate of perforation is closely connected with the factors that control anodic conditions, and conversely the tendency to pitting decreases as corrosion is scattered more uniformly over the exposed metal surface.

The purpose of this discussion is to add further emphasis to the importance of cleanliness as a factor in making for uniformity of attack. Particles of foreign matter, especially corrosion products that form over incipient pits, intensify the rate of attack at such points. When such material is removed before the pit has become too deep, the attack is usually shifted to another point. In this way corrosion is more uniformly distributed on metal that is frequently cleaned free from tubercles of rust or other deposits.

It is also evident that it is more important to maintain passive metals or alloys clean, such as stainless steel, than plain metals, such as carbon steel or copper-base alloys; for if dirt is allowed to accumulate, or incipient corrosion tubercles develop, the very dangerous combination of small active anodic area to large passive cathodic surfaces exists, which leads to rapid pitting.

★By R. B. Mears and R. H. Brown CORROSION 3, 97-120 (1947) Mar.

Cleanliness also improves the efficiency of inhibitors. In fact, localized attack is encouraged when insufficient amounts of anodic inhibitors such as sodium chromates are applied, but it has been shown[1, 2] that much less of the inhibitor is required to prevent corrosion when the metal is wiped free from incipient pits periodically. Anodic inhibitors can therefore be safely used in low concentration when the metal is swabbed regularly.

Cleaning metal surfaces, it will be seen, is a very important factor in corrosion control. A few instances where this simple remedy has been successfully applied are outlined briefly as follows:

In atmospheric corrosion, pipe handrails and railroad tracks kept clean by frequent use corrode without serious pitting—"busy metals do not corrode." The importance of regular inspection and cleaning has been pointed out in connection with safe maintenance of aircraft structures to combat destructive corrosion. Inadequate cleaning has materially reduced the service life of military aircraft, especially in the tropics. Periodic swabbing, we well know, is essential if the barrels of our shotguns are to be kept in A-1 condition.

In aqueous corrosion where the metal is much more liable to suffer by pitting, cleaning has a wider application; for instance, surface condenser tubes last much longer and serve more efficiently when regularly cleaned on the inside where water deposits and corrosion tubercles form. Suitable rubber swabs may be quickly shot through the tubes by air pressure. Water conduits, water mains, etc., also lose considerable carrying capacity from the increased wall friction caused by these accumulations.

Oil products pipelines carrying the lighter petroleum products become corroded with numerous small tubercles of rust, which within a few months materially reduce the flow unless protective measures are applied. This is due to the deposition of moisture from gasoline on the interior of the pipe as the temperature drops, and to dissolved oxygen in the fluid. Water soluble inhibitors such as sodium chromate or nitrite are effective, but rust deposits have been prevented and the flow capacity fully maintained by passing scrapers made up of two or three rubber discs through the line about every five days. More often the "rubber disc swabs" may be used less frequently when a water soluble inhibitor is employed. In either case a smooth interior without appreciable pitting can be maintained.

The foregoing few examples illustrate the important connection between metal cleanliness and the useful life of metals. In this respect they react somewhat like human beings—"Cleanliness is next to Godliness."

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Attenuation of Drainage Effects On a Long Uniform Structure With Distributed Drainage★

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IN A PAPER given last year[1] there are presented formulas for the attenuation of forced drainage currents and voltages to earth along a long uniform leaky structure. These formulas treat the situation where the forced drainage is applied at a single point or at points sufficiently separated so that there is no interaction between the drains. Frequently, forced drainage is applied at more or less regular intervals along a structure to order to provide more uniform cathodic protection and to avoid, as far as practicable, excessive negative potentials to earth near the drainage points.

The spacing of drainage points and the current drained at each point depend in large measure on practical considerations such as, ease of installing low-resistance grounds, proximity to power sources, right-of-way questions, etc.

In preliminary studies, however, it is convenient to be able to estimate from test data the effects that may be expected per ampere of drainage from a uniformly spaced series of drainage points. Using as a basis the formulas for the potential change of a structure to remote earth presented in the previous paper, expressions for the effects of equal drainage applied at uniform spacings will be developed here.

For purposes of this paper, it is convenient to divide drainage systems into two types:

1) Where the current is supplied by devices whose emf may be selected on the basis of requirements, such as rectifiers, motor generator sets, etc.
2) Where the current is supplied by fixed emf sources such as galvanic anodes.

The reason for this division will become evident later.

General

If an infinitely long buried structure is assumed to have uniform longitudinal conductivity and uniform leakage resistance to earth its resistance, R_K, to remote earth looking in one direction from any point

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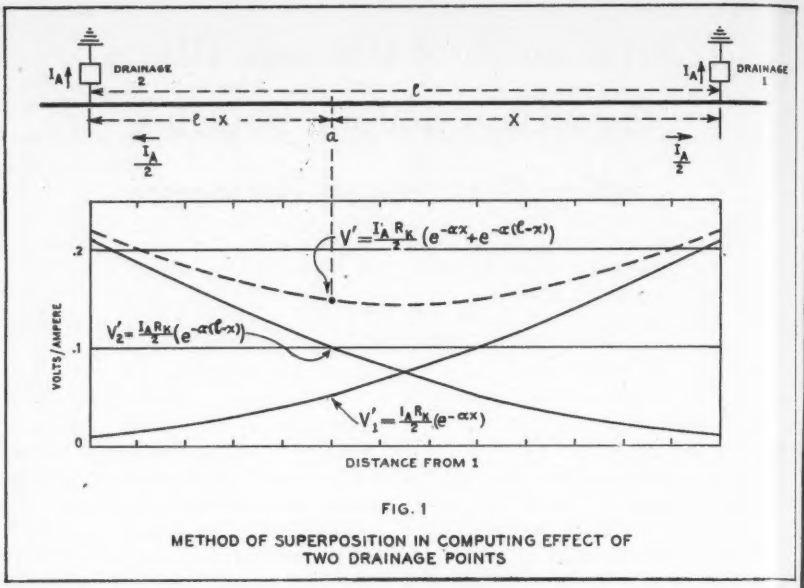


FIG. 1

METHOD OF SUPERPOSITION IN COMPUTING EFFECT OF TWO DRAINAGE POINTS

can be found by the usual uniform line formula and is:

$$R_K = \sqrt{R_S R_L} \qquad [1]$$

where: R_S = Longitudinal resistance in ohms per kilofoot,

and R_L = Leakage resistance in kilofoot-ohms.

Also, if V_0 is the change in the potential of the structure to remote earth per ampere of current removed from the structure at any point, the change in structure potential at a point distant x kilofeet from the drainage point is:

$$V_x = V_0 e^{-\alpha x} \qquad [2]$$

where α is the attenuation constant of the structure and is equal to,

$$\sqrt{\frac{R_S}{R_L}}$$

If a drainage current of I_A amperes is taken off such a structure at any point to a remote anode, the current will come equally from each direction along the structure and the change in structure potential to remote earth at the drainage point caused by I_A will be:

$$V_0 = \frac{I_A R_K}{2} \qquad [3]$$

Thus, with a knowledge of the structure constants, which may be either computed or measured, it is possible by means of expressions 1, 2 and 3 above to estimate the potential change that can be expected at any point along a uniform structure due to drainage at a single point.

When there is more than one drainage point, the potential change at any point on the structure can be obtained by superposition. That is, by computing the effect of each drainage separately on a particular point and then adding the individual effects to obtain the total effect. For instance, assume two drainage points

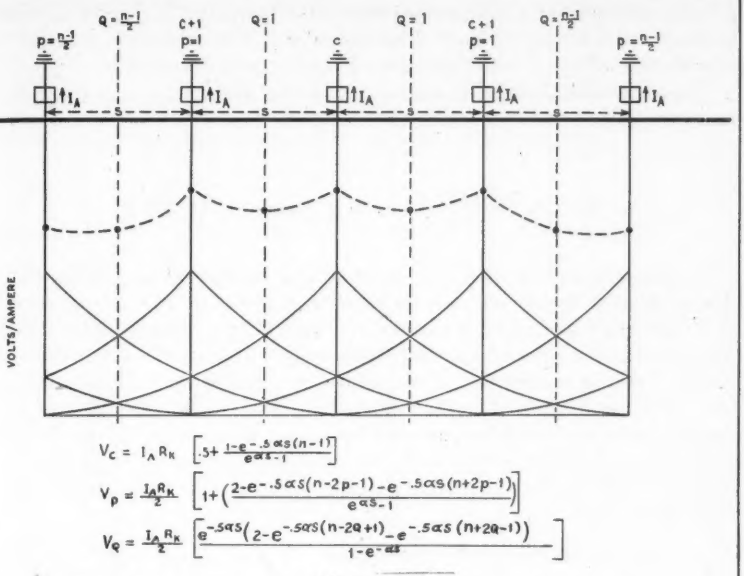


FIG. 2

POTENTIAL CHANGE AT DRAINAGE POINTS AND AT POINTS MIDWAY BETWEEN DRAINAGE POINTS FOR n EQUAL DRAINERS SPACED 5 KILOFEET

each draining I_A amperes and separated by l kilofeet, as indicated on Figure 1. The potential change at point a, x kilofeet from drainage 1 would be, due to drainage 1;

$$V_{a-1} = \frac{I_A R_K}{2} \cdot e^{-\alpha x}$$

and due to drainage 2;

$$V_{a-2} = \frac{I_A R_K}{2} \cdot e^{-\alpha(l-x)}$$

The change due to both drainages would be the sum of these two changes, i.e.,

$$V_{a-1} + V_{a-2} = \frac{I_A R_K}{2} (e^{-\alpha x} + e^{-\alpha(l-x)})$$

This process may be repeated for other points between the drainage points and a plot developed as indicated on Figure 1.

In the case where a number of forced drainage points at regular spacing and of equal current are contemplated, the above method can be used to estimate the cumulative effect at any point. However, if uniform conditions are assumed, general expressions for the effects at salient points within the system such as at particular drainage points and at points midway between particular pairs of drainage points may be developed. With this information, the effect at intermediate points may be estimated graphically.

Rectifier and Similar Drainage Systems

Consider a long uniform structure with n drainage points spaced at regular intervals of s kilofeet, each

draining I_A amperes. (It is convenient in this development to assume that n is an odd number.) This arrangement is illustrated in Figure 2, which also indicates the effect of each drainage along the structure, as well as the cumulative effect of all drainages operating simultaneously.

The potential change at the center of the system (c on Figure 2) is, by summation:

$$V_c = \frac{I_A R_K}{2} + \frac{I_A R_K}{2}\left[e^{-\alpha_s} + e^{-2\alpha_s} + \ldots e^{-\left(\frac{n-1}{2}\right)\alpha_s}\right]2 \qquad [4]$$

In this expression, the first term is the change produced at the center drainage point by the current removed at that point. The second term represents the effects of all of the other drainage points, attenuated to the center. The quantity in parentheses represents the effect of all of the drainages on one side of the center and is, therefore, multiplied by 2 in order to account for a like number on the other side. This quantity in parentheses is a geometric series and may be summed up in the usual way. When this is done, and other reductions performed, the following expression is obtained for the combined effect on the structure to the remote earth potential at the center drainage point:

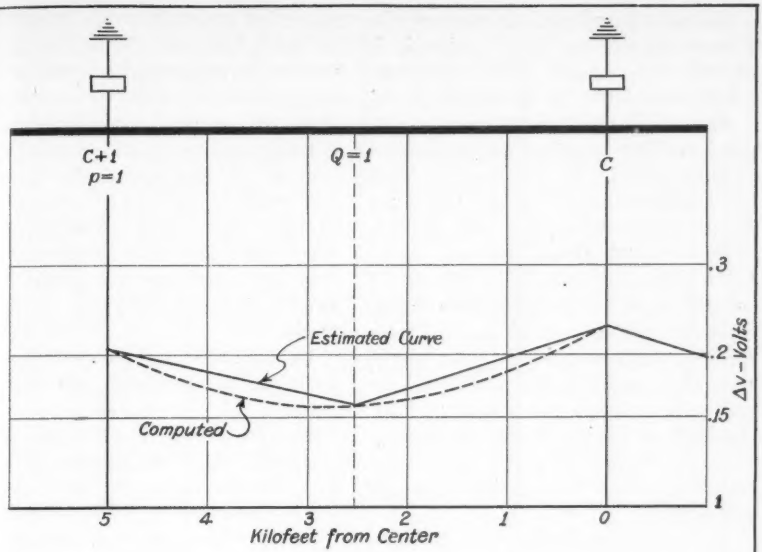
$$V_c = I_A R_K\left[.5 + \frac{1 - e^{-.5\alpha_s(n-1)}}{e^{\alpha_s - 1}}\right] \qquad [5]$$

At the first pair of drainage points off center (c + 1 in Figure 2) the potential change to remote earth will be:

$$V_{c+1} = \frac{I_A R_K}{2} + \frac{I_A R_K}{2}\left[e^{-\alpha_s} + e^{-2\alpha_s} + \ldots e^{-\left(\frac{n-3}{2}\right)\alpha_s}\right] + \frac{I_A R_K}{2}\left[e^{-\alpha_s} + e^{-2\alpha_s} + \ldots e^{-\left(\frac{n-1}{2}\right)\alpha_s}\right] \qquad [6]$$

In this expression the first term, as before, is the effect at the drainage point in question due to its own current. The second term is the cumulative effect of all drainage points in one direction and the third term is the cumulative effect of all drainage points in the other direction. If p is assigned to represent the position of the drainage point at which the potential change is desired with respect to the center of the system, (that is, for the first point off center $p = 1$, for the second $p = 2$ etc., and for the last point $p = \frac{n-1}{2}$) the following general expression is obtained:

$$V_P = \frac{I_A R_K}{2}\left[1 + \frac{2 - e^{-.5\alpha_s(n-2p-1)} - e^{-.5\alpha_s(n+2p-1)}}{e^{\alpha_s - 1}}\right] \qquad [7]$$



$R_L = .1$ ohm/kf, $R_S = 1$ kilofoot-ohm, $R_K = \sqrt{R_S R_L} = .316$ ohm

$\alpha = \sqrt{\frac{R_S}{R_L}} = .316$ $S = 5$ Kf, $n = 3$

FIG. 3

EFFECT OF THREE EQUAL DRAINAGE POINTS SPACED 5 KF APART ON SINGLE FULL SIZE TELEPHONE CABLE IN CONDUIT

The expression for the potential change at points midway between drainage points is similarly obtained and is as follows:

$$V_Q = \frac{I_A R_K}{2}\left[\frac{e^{-.5\alpha s}\left(2 - e^{-.5\alpha s\,(n-2Q+1)} - e^{-.5\alpha s\,(n+2Q-1)}\right)}{1 - e^{-\alpha s}}\right] \qquad [8]$$

When Q represents the position with respect to the center (i.e. for the first pair of mid points off center $Q = 1$, for the second $Q = 2$, etc.).

For an example of the use of the above expressions, assume that it is desired to install three drainage points at 5-kilofoot intervals along a single full size telephone cable in conduit. The longitudinal resistance of such a cable, R_S, is about 0.1 ohm per kilofoot and a leakage resistance R_L of 1 kilofoot-ohm will be assumed. From these figures, $R_K = 0.316$ ohms and $\alpha = 0.316$ (R_K and α are not necessarily equal numerically. This is just a coincidence.) These values, substituted in the above equations provide the points on the potential change per ampere chart, plotted on Figure 3. Since the system is symmetrical about the center, only the effects to one side of center are shown.

If it is assumed that the potential change at the points midway between drainages is the minimum change that occurs between a particular pair of drainage points, the effects at intermediate points may be estimated by plotting the computed points on semi-log paper and joining them by straight lines. This construction is an approximation because actually the points of minimum potential change lie to the left of the midpoint, and the curve is not a straight line on semi-log paper. The resulting error is slight, however, as indicated on Figure 3, which shows the computed curve as well as the estimated curve.

In the above formulas it was assumed that the drainage currents were independent of one another; that is, that the addition of successive rectifiers to the system did not affect the drainage current of those already in place. With rectifiers or similar devices as the sources of drainage currents on fairly well-grounded structures this assumption is valid because the emf's of the sources are generally considerably larger than the changes in structure-to-earth potential produced at the drainage points by the next adjacent sources. In any event, the formulas are valid if, with all sources connected, successive adjustments in their emf's are made until all of the drainage currents are equal. Such adjustments conceivably could be made.

In the case of galvanic anodes, such an assumption is not valid because:

1) The change in structure potential may no longer be small compared to the drainage emf.
2) The drainage emf is fixed.

It therefore becomes necessary to adopt a little different approach. The rigorous development of formulas to represent conditions becomes very complex and the formulas for even a few drainage points are unwieldy. By making certain approximations, however, it is possible to obtain expressions that are simple and reasonably accurate.

As in the case of rectifier drainage, assume a system of n drainage points, this time supplied by galvanic anodes, distributed along a structure at regular spacings of s kilofeet. (Again, n is an odd number.) If the anode currents are assumed to be equal, the expression for the potential change at the midpoint of the distributed system is the same as given before in Equation 4. Also, if the open circuit galvanic potential between the structure is E_G, and the resistance to ground of the individual anodes is R_A, the current at each drainage point with all others disconnected is

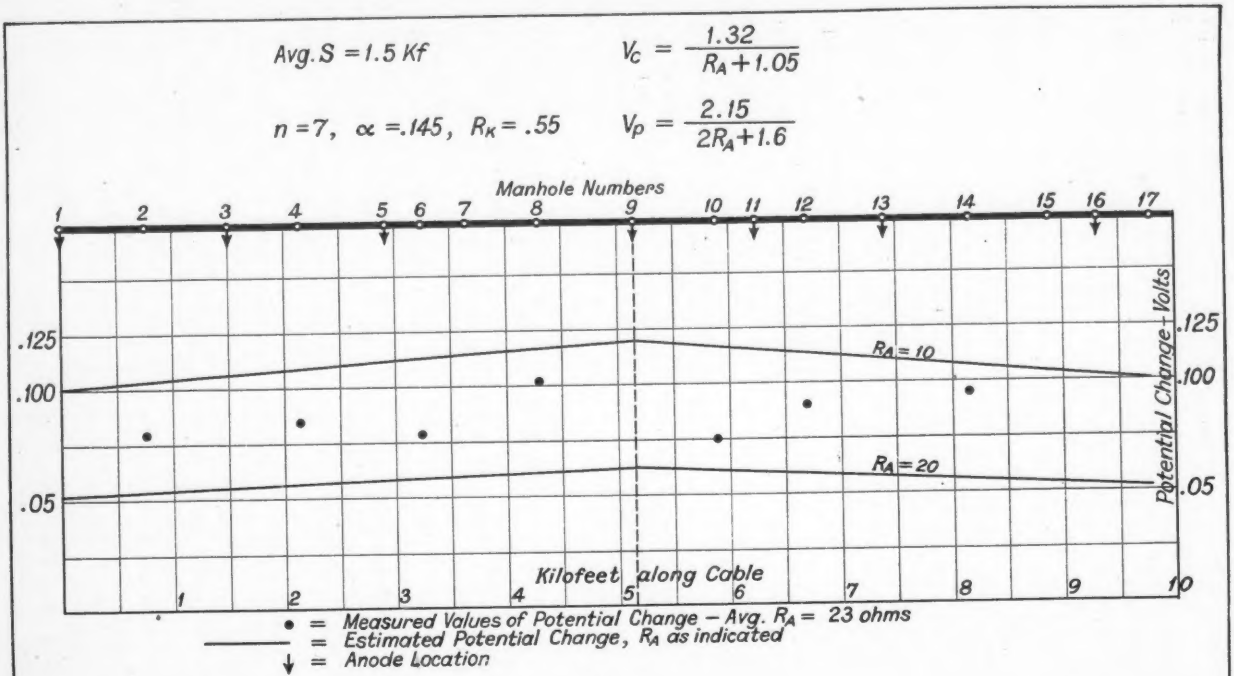

Avg. S = 1.5 Kf
$V_C = \frac{1.32}{R_A + 1.05}$
n = 7, α = .145, R_K = .55
$V_P = \frac{2.15}{2R_A + 1.6}$
Manhole Numbers
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
.125
.100
.05
R_A = 10
R_A = 20
Potential Change - Volts
Kilofeet along Cable
1 2 3 4 5 6 7 8 9 10
• = Measured Values of Potential Change – Avg. R_A = 23 ohms
——— = Estimated Potential Change, R_A as indicated
↓ = Anode Location

FIG. 4
EFFECT OF DISTRIBUTED MAGNESIUM ANODES
ON TELEPHONE CABLE IN CONDUIT

approximately:

$$I = \frac{E_G}{R_A} \qquad [9]$$

This assumes that the characteristic resistance of the structure is negligibly small compared to the anode ground resistance, a fair assumption for most cases. If, however, with all anodes connected to the structure, one of them is opened, the open-circuit potential between it and the structure will be smaller than E_G by the change in structure-to-earth potential caused by all of the other operating anodes. This reduction in effective anode potential will be different at each anode, depending on the position of the particular anode in the distributed system. This effect may be accounted for rigorously but as mentioned earlier, the resulting expressions are complicated and unwieldy. If it is assumed, however, that the reduction is the same at all points and that it is equal to the change at the center anode location, the following relatively simple expressions for the current at the anode result:

$$I_c = \frac{E_G - \left[e^{-\alpha_s} + e^{-2\alpha_s} + \ldots e^{-\left(\frac{n-1}{2}\right)-\alpha_s} \right] I_c R_K}{R_A} \qquad [10]$$

as before, this expression reduces to:

$$I_c = \frac{E_G - \left[e^{-\alpha_s}\left(1 - e^{-\frac{n-1}{2}\alpha_s}\right) \right] I_c R_K}{\frac{1 - e^{-\alpha_s}}{R_A}} \qquad [11]$$

solving for I_c gives:

$$I_c = \frac{E_G - \left[\frac{1 - e^{-.5\alpha_s (n-1)}}{e^{\alpha_s - 1}} \right]}{R_A} \qquad [12]$$

If it is now assumed that I_c exists at all of the anode locations, the above value may be substituted for I_A in Equation 5 to obtain the structure-to-earth potential change at the center anode. This substitution gives:

$$V_c = \left[\frac{.5 + U}{\frac{R_A}{R_K} + U} \right] E_G \qquad [13]$$

where: $U = \frac{1 - e^{-.5\alpha_s (n-1)}}{e^{\alpha_s - 1}}$

The potential change at the last anode can be similarly determined under the assumption that the reduction in effective anode potential is equal to the reduction at the last anode. This assumption results in the following expression for the structure-to-earth potential change at the last anode:

$$V_n = \left[\frac{1 + V}{\frac{2R_A}{R_K} + V} \right] E_G \qquad [14]$$

where: $V = \frac{1 - e^{-\alpha_s (n-1)}}{e^{\alpha_s - 1}}$

From the above equations the potential change of the structure to remote earth may be found for the center and the two ends of the distributed drainage system. With this information, the change at intermediate points may be approximated by plotting the points so determined and connecting them with a straight line. In this case, ordinary graph paper may be used because the spacing between anodes is ordinarily so small that little attenuation takes place between them and the added accuracy of semi-log paper, is therefore, not warranted.

The process of successive assump

tions resorted to above can only be justified on the basis that the resulting expressions are approximations. It has been found, however, by checking against more rigorously determined expressions, that the final approximate formulas are reasonably accurate, particularly when R_K is less than about $4R_A$, a condition that will be generally met except, possibly, in the case of well-coated lines or cables.

As an illustration of the use of these formulas for the effects of galvanic anodes, experience in a practical case may be of interest. For example, two telephone cables having a combined longitudinal resistance of 0.077 ohm per kilofoot extended in conduit for a distance of about 10 kilofeet along the edge of a highway. At one end of the section the cables were spliced through into a conduit system containing additional cables, while at the other end they were connected to aerial cables that extended for about 20 miles before entering underground conduit. In this 10-kilofoot section it was desired to install sufficient cathodic protection to shift the potential of the cables by about 0.1 volt to remote earth, and distributed magnesium anodes were considered.

Figure 4 shows the cable layout along with the location of manholes where connections could be made to the sheaths. A few preliminary tests indicated that R_K was about 0.55 ohms and α about 0.145. Assuming the installation of seven anodes at manholes 1, 3, 5, 9, 11, 13, and 16, the average spacing between anodes would be about 1.6 kilofeet. Substituting the above values in the formulas for V_e and V_p gave:

$$V_e = \frac{1.32}{R_A + 1.05}$$

$$V_p = \frac{2.14}{2R_A + 1.6}$$

The earth resistivity in this area is such that single 4-inch x 20-inch magnesium anodes might be expected to have a resistance to ground of between 10 and 20 ohms. Using these two extremes in the above expressions for V_e and V_p yielded the plots shown on Figure 4.

The anodes were installed as originally planned and, disregarding one of them whose resistance was very high, had an average resistance of about 20 ohms. Measurements of cable-to-earth potential change were made after the anodes were installed, and the results are plotted on Figure 4.

The measured change is somewhat larger than would be expected from the estimates. This is believed to be due in part to the fact that the measurements of cable-to-earth potential with the anodes operating were not made until about a week after the installation was made and thus some polarization of the cable had probably taken place. The difference might also be caused by voltage gradients around the anodes although this would not seem likely since the measurements were made at points intermediate between anode locations specifically to avoid this effect which is not included in the formulas.

Reference

1. Pope, Robert, Attenuation of Forced Drainage Currents on Long Uniform Structures, Corrosion **2**, 307, December (1946).

Appreciation

To Corporate and Associate Members of the National Association of Corrosion Engineers

Listed below are the industrial companies and public utilities who contribute toward furthering NACE work in the field of corrosion, and make possible, among other things, sponsoring of technical committees and publication of the Association journal, Corrosion. Their contribution enables the Association to publish scientific and technical papers in the journal, Corrosion, which provides a comprehensive technical information service for the benefit of all industry.

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Our Billion-Dollar Side Show*

. . . For Managers Only

By H. H. Anderson
Vice President, Shell Pipe Line Corporation, Houston, Texas

WHEN MIKE JACOBS can draw a million-dollar gate for a one-round main event, we concede that Barnum was right. But what about us in industry who are needlessly paying billions† for a show we can't even see? I refer to soil corrosion—Nature's relentless attack on our buried pipe lines, power and communications cables, rail systems and other metal structures. And I say "needlessly" because much of the damage can be stopped by cathodic protection if we will appreciate and apply this simple principle disclosed by Sir Humphry Davy in 1824!

A Speaking Acquaintance

Cathodic protection can save industry from myriad costly service breakdowns, commodity losses, customer ill-will and plant repairs and renewals. Yet many corrosion engineers tell me that a prime limitation on its use is that management is not yet sold on it. These ardent exponents know how simply it works, how great is its value, how tangible is its economy, and how it warrants broader acceptance. Thus I suspect many engineers have confused instead of enlightened the boss with too much detail while trying to explain facts that seem obvious to them. Believing that every operating executive owes it to his business to be at least on speaking terms with cathodic protection, I beg to introduce you herewith.

Let's raise the iron curtain on this billion-dollar show. We started it ourselves when we buried our refined metal structure bare (or practically so) in the soil. This upset Mother Nature's age-old chemical balance, and the old dame promptly started soil corrosion at work to restore it. Soil corrosion of metal is caused by a localized attack of soil

• CATHODIC Proctection is deemed so important that eight industry associations, the two nation-wide communications systems and a professional association recently joined their effort in a committee to inform managers about it, to promote cooperation within and between industries in applying it, and to aid the local solution of its technical problems. This work will take time. Thus, as Chairman of the Correlating Committee on Cathodic Protection, I am presuming personally to "jump the gun" with this direct appeal to management for understanding and cooperation.

H. H. Anderson

★ A paper presented at the annual meeting of NACE in Chicago, Ill., April 7-10, 1947.

† According to Bureau of Standards Circular C-450, the annual cost of pipe line replacements due to corrosion is approximately 200 million dollars per year! This does not take into account the costs of replacing various other types of plant suffering from soil corrosion.

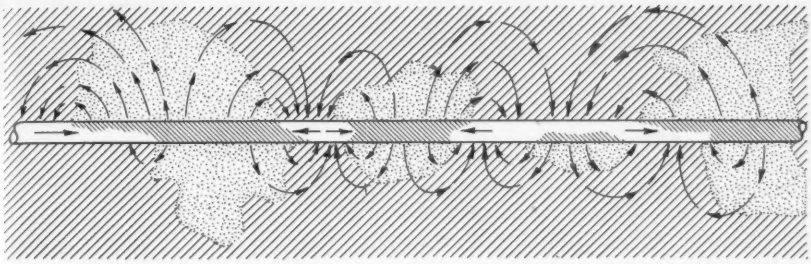


Figure 1—Series of batteries caused by attack of patches of sour or moist soils along a structure. Arrows show currents flowing from anodic areas (areas of attack) to cathodic areas.

chemical solutions. It starts where the soil is more moist and acid or alkaline than average, or it can start at a defect in the metal surface. It generates electric currents which flow from the point of attack out through the soil back elsewhere to the metal.

Assault and Battery

You recall that in a common battery the solution attacks the zinc or baser metal, called the "anode," to generate a current. This current flows out through the solution to the carbon, called the "cathode," thence through a metallic circuit back to the anode. And what of our buried structure? Contacted by the varying soil solutions of Nature, its bare surface serves both as anode (the area under attack) and as cathode (the rest of its surface) because its metallic continuity forms a circuit between them. As shown in Figure 1, if our structure is long (or is of large area) it can be a part of many such natural batteries, and thus it can have a series of anodic and cathodic sections.

Jekyll and Hyde

Soil moisture, that well-known H_2O, plays a dual role in our subterranean melodrama. Figure 2 shows a molecule at work! During the chemical attack some of the water divides into hydrogen and oxygen, each going its separate way. Oxygen is the one that attacks our structure.

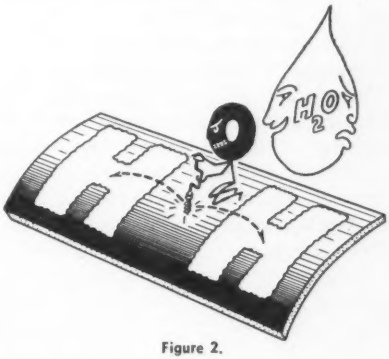


Figure 2.

Its corrosive atoms create an anode, which responds with a weak but determined electric force that sends currents out through the soil seeking a cathode. But hydrogen rushes to the rescue. Its atoms ride the currents through the soil and cover the rest of the bare surface. Soil chemicals cannot pierce the hydrogen film, thus it shields all but the immediate area under attack; i.e., it protects the metal by forming a cathode. Eureka!

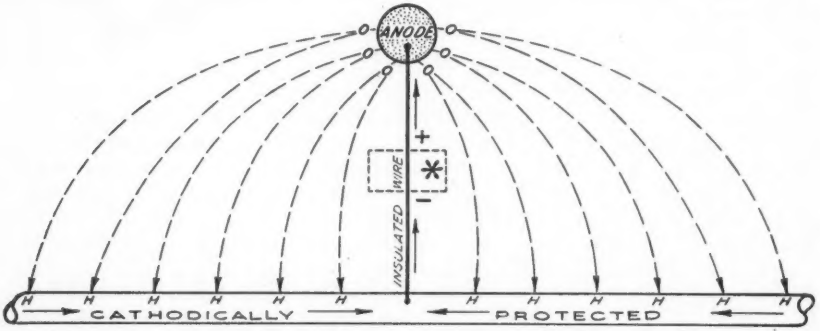
There's a clue to cathodic protection. If we can cover *all* of the surface with enough hydrogen we may protect it completely.

The Sacrifice

And how is this to be done? As they say in the movies, we merely get a "stand-in" or a substitute anode. Through it we can apply other currents strong enough to enter our structure's entire surface via the soil, thus overpowering and reversing the local battery currents trying to leave. The simplest way to protect a steel or lead structure is to merely bury a chunk of baser metal (such as magnesium, aluminum or zinc) near the structure, and connect the two by an insulated wire. Oxygen has a greater affinity for this baser metal, so—as long as the two are connected by the wire—it instead attacks the baser metal! This responds more vigorously and forces much stronger currents out through the soil en route to our structure. As shown in Figure 3, hydrogen again rides them all and makes a cathode of its entire surface—even the areas before under attack. The currents return from the structure to the baser metal anode through the wire. In the process, the baser metal instead of our structure is slowly oxidized or corroded away. Biblically speaking, it lays down its life for a friend. That's why we call it a sacrificial (or "galvanic") anode.

A Knock-Out Punch

Some soils are so corrosive as to require stronger measures. Here we may bury a mass of junk iron or steel (or a carbon rod) nearby to serve as the anode. Then with insulated wires we connect a strong external direct-current source, such as a ten-volt generator or rectifier, (+) to the junk and (—) to the structure. The generated currents force their way from the junk anode through the soil into the structure and smother it with hydrogen. The junk will be eaten away in time and must be replaced. A single such unit, being ten times more powerful than a galvanic anode, can protect several miles of structure under some conditions. The choice of a current-supply in each case poses some nice problems, not only in meeting the need



* Generator may be placed here if galvanic anode is not used.

Figure 3—Long structure showing currents from buried anode entering structure. All oxygen attack is at anode. Structure is entirely protected by hydrogen.

but also in the balancing of first costs versus recurring expenses.

Rags and Tatters

Our buried structure can be protected also with special enamels or coatings. But only during the last few years have we learned how to apply these properly. There's many a mile (and acre) of structure with defective coatings; and these may be worse than none because such defects act to focus corrosion and localize pitting. What are we to do about them? The cold sod is a poor and expensive place in which to apply new coatings, anyhow. Thus, if our structure's present coat is tattered, cathodic protection may provide safety with economy.

They Hide the Body

When installing new metal structures, many shrewd operators know that a modern enamel coating, properly applied, plus *some* cathodic protection is best economy in the long run. They never can infallibly predict the soil action along a new route, and they know it costs about five times as much to later dig up, clean, repair and coat a line than to coat it right in the first place. They know also that a bare metal structure must be extra thick to allow for corrosion pitting, and that this extra metal costs about as much as a good coating. But even the best of coatings may develop defects (either while being buried or later); so a light supply of hydrogen should be on guard to fill the holes. Thus *some* cathodic protection is good insurance even on a newly-coated line.

At the Crossroads

It looks as if that should end our troubles, but no. For better or worse, every current must flow back to its source. If a neighbor's metal structure is adjacent, or if it crosses but does not touch ours, and it is within the field of the currents flowing from our protective anodes to our structure, some of the generated current may possibly "stray" into his structure (which provides a low-resistance path) and flow through it to the point nearest ours. There the current must leave his structure to jump through the soil back into ours and return to its source. We saw before that chemical attack on metal will cause current flow. Well, it also works in reverse! Where our stray current leaves his structure to enter the soil, it may cause chemical attack or local corrosion. This action is called "electrolysis."

Out of the Pit

Electrolysis can be as bad as true soil corrosion because, with either one, a current flow of one ampere in a year will destroy 20 pounds of steel or iron, or 75 pounds of lead. And both usually focus to cause pitholes which soon pierce our structure. Electrolysis can be avoided by connecting a resistant wire or "bond" between the two structures to drain the returning stray current from the adjacent structure into the protected one. This "drainage bond" must be well-designed, however, because too little drainage will not stop the interference, while too much will give our neighbor real cathodic protection at our expense. We want to be friends, don't we—but not philanthropists! It was said above that a good coating reduces the current needed to cathodically protect our structure. The lesser cur-

rent, in turn, reduces the chance for electrolysis to occur!

City Slickers

Strong stray currents from electric railway tracks have long caused electrolysis of other buried structures in cities. Several competent local committees have worked for years to minimize this action. However, with the steady conversion by transit companies to motor-bus and double-trolley coach service, that trouble is abating through removal of its cause. Conversely, true soil corrosion is spreading in cities because removal of the stray currents allows the weaker currents of Nature's batteries to flow unopposed. Thus city operators, too, must increase their interest in cathodic protection.

The Denouement

If we want to use cathodic protection, we can ill-afford to interfere with neighboring structures by electrolysis. Yes, and our neighbors can ill-afford to have this done. But decorum tells us that our corrosion engineer should not trespass the other structures—even to make the tests needed to design the drainage bonds. However, if our neighbors also are acquainted with the problem and will cooperate for the common good, they will welcome the tests, the technical details can be readily worked out, the bonds can be installed and all structures will be benefited.

Often we may want to install cathodic protection where a neighbor's structure parallels ours for quite a distance. Then his structure will absorb much of our precious current and need several drainage bonds merely to prevent interference. Here we often can save money by inducing him to install cathodic protection, too. And why not, if his structure lies in the same corrosive soils? Several large companies have installed many protection units jointly. Capital as well as operating expenses are shared equitably, and with mutual satisfaction. Here, again, acquaintance with the general problem at the management level aids the engineers to work for maximum protection and economy. Such results help the customers, and please the stockholders.

Summing It Up

As the curtain drops on our show, we can take stock. Does cathodic protection work simply? In essence, yes; we just get a current source or anode and spray on a little hydrogen. Is its value great? Why not—if it stops corrosion. Does it need a special kind of cooperation? It doesn't if we are all acquainted with its problems and will follow the Golden Rule. But what about its tangible economy? If you are not already sold, a good corrosion engineer probably can prescribe it for your own structures and soon convince you of its economy. But to stress my main point, you can see that cooperation with others in cathodic protection is good business.

The problems of cathodic protection aren't really as simple as I've made them seem. Their solutions call for data, science and experience mixed with plenty of plain horse-sense. But our corrosion engineers will work them out for us and thereby lessen industry's heavy losses from soil corrosion to the extent that we afford them the opportunity and lend our sympathetic support!

NACE News

Technical Committee Is Formed to Study Anodes For Use With Impressed Current

A NEW technical committee, to be known as the "Anodes for Use With Impressed Current," has been formed for purpose of making field tests on various anode materials. Donald H. Bond, The Texas Pipe Line Co., Houston, Texas, was named chairman of the new committee, with membership as follows:

W. A. Broome, Louisiana Arkansas Gas Co., Shreveport, La.

Lee N. Spinks, United Gas Pipe Line Co., Shreveport, La.

J. P. Oliver, National Carbon Co., Cleveland, Ohio.

Derk Holsteyn, Shell Oil Co., Inc., Houston, Texas.

O. C. Roddey, Interstate Natural Gas Co., Monroe, La.

R. D. McClintock, Colorado Interstate Gas Co., Colorado Springs, Colo.

A. W. Peabody, Ebasco Services, Inc., New York, N. Y.

The ground work for the new committee was laid last January, when, at a meeting held in the offices of G. R. Olson, United Gas Pipe Line Co., Shreveport, La., plans for a group to conduct field tests on carbon and graphite anodes were discussed and formulated. A temporary committee was named, with the hope that National Association of Corrosion Engineers would see fit later to appoint a permanent committee. At the April conference, NACE accepted the entire group of temporary committeemen, and Mr. Peabody was added.

At the January meeting, the National Carbon Co., which had been conducting laboratory tests on carbon and graphite anodes, volunteered to furnish the necessary materials to those companies offering to coöperate in the tests. Tests were to be run on different size anodes using various backfills, including backfills treated with sodium chloride. The test combinations proposed then are as follows:

Proposed Ground Anode Field Test

	Item No.	TYPE INSTALLATION	Size Anode	No. Required
Ground Bed No. 1	1	Carbon—Natural Soil	4″ x 80″	4
	2	Graphite—Natural Soil	4″ x 80″	4
	3	Iron Pipe—Natural Soil	4″ x 80″	4
Ground Bed No. 2	4	Graphite—Coke Breeze	2″ x 80″	4
	5	Graphite—Graphite	2″ x 80″	4
	6	Graphite—Graphite/Lime	2″ x 80″	4
	7	Iron Pipe—Coke Breeze	2″ x 80″	4
Ground Bed No. 3	5	Graphite—Graphite	2″ x 80″	4
	8	Graphite—Coke Breeze and Lime	2″ x 80″	4
	7	Iron Pipe—Coke Breeze	2″ x 80″	4
	3	Graphite—Natural Soil	4″ x 80″	4
Ground Bed No. 4	4	Graphite—Coke Breeze	2″ x 80″	4
	9	Short Graphite—Coke Breeze	4″ x 40″	4
	10	Carbon—Coke Breeze	2″ x 80″	4
	11	Graphite—Gypsum	4″ x 80″	4
Ground Bed No. 5	12	Graphite—Salt and Natural Soil	2″ x 80″	4
	13	Graphite—Salt and Bentonite	2″ x 80″	4
	14	Graphite—Salt and Coke Breeze	2″ x 80″	4
	14	Graphite—Coke Breeze and Bentonite	2″ x 80″	4

The following limiting conditions were proposed for the various tests:

1) Current density:
   Maximum value not to exceed 4 amperes for 4″ x 80″ rod, and 2 amperes for 2″ x 80″ rod.
2) Diameter of hole used:
   Three times diameter of rod.
3) Spacing:
   15 feet on centers.

Offers were made to make installations as follows:

Company	No. of Anodes
1) Louisiana-Arkansas Gas Co. (Mr. Broome)	16-2″ anodes
2) Interstate Natural Gas Co. (Mr. Roddey)	16-2″ anodes
3) The Texas Pipe Line Co. (Mr. Bond)	Complete Test

The total number of anodes required for the above tests were all that were available at the time. It is expected that additional tests may be arranged later, in order to include a variety of soil and moisture conditions. It was also advanced during the January meeting, that the then scheduled tests would not be complete and sufficient for the purpose intended, but would be at least of great value in planning future investigations. It is expected that various new ideas and suggestions will be forthcoming from many interested parties, which may be incorporated as soon as suitable arrangements can be effected. A report will be made by Mr. Bond next month.

North East Meeting

THE technical program for the North East Regional meeting of NACE, to be held June 9 in Pittsburgh, is as follows:

AFTERNOON

The Behavior of Hydrogen in Steel During and After Immersion in Acid, *L. S. Darken*, Research Laboratory, U. S. Steel Corp., Kearny, N. J.

The Effect of Hydrogen Generated by Corrosion of Steel, *M. E. Holmberg*, Engineering Department, Phillips Petroleum Co., Bartlesville, Okla.

EVENING

The Effect of Carbide Structure on the Corrosion Resistance of Steel, *F. A. Prange*, Engineering Department, Phillips Petroleum Co., Bartlesville, Okla.

LaQue Will Represent NACE at Paris Corrosion Congress

F. L. LaQUE, International Nickel Co., New York and Vice President of the National Association of Corrosion Engineers, has been selected to represent the Association at the Corrosion Congress, to be held in October of this year in Paris, France. It is understood that one of the purposes of a representative at the Corrosion Congress is to coöperate with the French in assisting them to secure that information on research and development in the field of corrosion which they missed during the past years, when practically all of France was out of touch with the outside world, and had been unable to keep informed on scientific and technical developments. It is also understood that NACE will coöperate, providing there does not develop some presently unknown international limitation or complication. The matter is now under investigation by the Policy and Planning Committee, who will advise Mr. LaQue on steps to be taken as representative of the Association during the Corrosion Congress.

New Technical Committee

AT THE PRESENT TIME there are three technical committees in the National Association of Corrosion Engineers. These are committees on:

1. Condensate Well Corrosion.

2. Galvanic Anodes for Cathodic Protection.

3. Anodes for Use with Impressed Current.

It is planned to initiate a fourth committee on Minimum Current Requirements for Cathodic Protection in the near future.

There have been suggestions that committees should be set up to investigate the following:

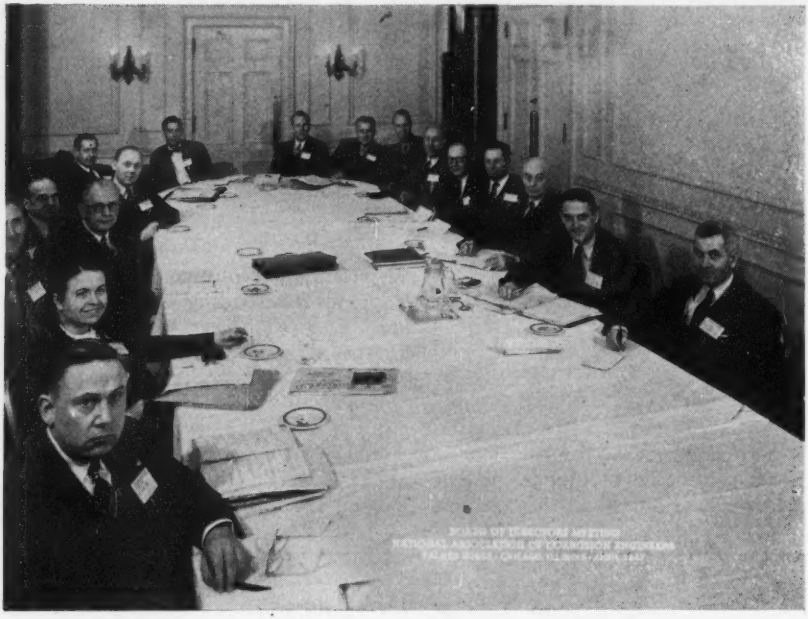
A. Sand Packs for Preventing Underground Corrosion.
B. Selections of Materials for Grounding Purposes at Generating Plants and Sub-Stations.
C. Organic Coatings for Oil Field Equipment.
D. Selection of Materials for Gaskets, Packing and Insulation.
E. High Temperature Corrosion.
F. Corrosion by Industrial Waters.

Before attempting to initiate new committee work, it is desirable to learn whether there is sufficient interest in the problem so that the new committee is justified. Therefore, it is requested that all members interested in any of the topics listed under A to F above write the Chairman of the Technical Practices Committee expressing their interest. If any member wishes to have some additional corrosion or protection problem studied by a technical committee, he should also make this suggestion.

This is your chance to make certain that our Society takes steps to study your problems. Take advantage of it by sending your suggestions to the Technical Practices Committee.

(Signed) *R. B. Mears, Chairman**
Technical Practices Committee.

* Address: Research Laboratory, Carnegie-Illinois Steel Corp., 210 Semple St., Pittsburgh, Pa.



President G. R. Olson presides over Board of Directors meeting, held April 10, 1947 in Chicago. Seated from left to right around table are: Robert Pope, Ivy M. Parker, V. M. Jenkins, H. M. Trueblood, Treasurer O. C. Mudd, H. J. McDonald, F. J. McElhatton, A. Smith, Jr., F. L. Goldsby, H. B. Britton, E. L. Rolfs, L. F. Scherer, L. A. Baldwin, T. L. Holcombe, Executive Secretary A. B. Campbell, President Olson, and Vice President F. L. LaQue.

Members in the Shreveport, La., area have petitioned, through the South Central Regional Director of National Association of Corrosion Engineers, L. F. Scherer, The Texas Pipe Line Co., Houston, Texas, for recognition as a section.

At the April 6 Board of Directors meeting, it was ruled that the names of five Regional Divisions of the parent Association will be as follows:

North East
South Central
South East
North Central
Western.

Fred L. Goldsby, Chicago Bridge & Iron Works, Chicago, has taken over the duties of chairman of the General Committee for the 1948 NACE Conference and Exhibition, to be held at the Jefferson Hotel in St. Louis April 5 through 8. Mr. Goldsby is now selecting his various committeemen.

Mars G. Fontana, the Ohio State University, Columbus, Ohio, is handling the chairmanship of the Technical Program Committee for the 1948 Conference, and will arrange for speakers and papers for the various symposia.

General Interest

Another forward stride in the oil industry's program to conserve natural gas was made in the South Texas area when construction started on the Tomoconnor Natural Gasoline Plant some 15 miles northeast of Refugio. The plant is being built jointly by Humble Oil & Refining Co., and Quintana Gas Co., at a cost of approximately $3 millions. The plant is scheduled for completion this fall. Plans call for the installation of stripping equipment to handle a maximum of 35 million cubic feet of casinghead gas a day and compression equipment for between 25 and 30 million cubic feet a day. Most of the gas is being flared at the present.

Niagara Hudson Power Corp., Syracuse, N. Y., has set plans for a five-year $100 million improvement program which will spread out over the next five years and bring about extension and improvement of the company's service through New York State. Expenditure will be made for additional power-generating stations and transformers, for extension of rural electric lines and extensions to the company's steam stations in Buffalo and Oswego.

Johns-Manville Corp., New York, purchased the Goetze Gasket & Packing Co., Inc., New Brunswick, N. J., manufacturer of metallic gaskets. The product will be produced as formerly under the Goetze name.

E. I. du Pont de Nemours & Co. has C.P.A. approval for $100,000 remodeling project for its laboratory at Flint, Mich.

Electro Rust-Proofing Corporation, Belleville, New Jersey, has announced the appointment of Mr. Frank P. Macdonald as sales manager. Mr. Macdonald will make his headquarters in the Wallace & Tiernan building at 1229 West Washington Boulevard, Chicago. Mr. Macdonald has been with Electro Rust-Proofing for a number of years and has had wide experience in the field of cathodic protection. His appointment is part of the company's plan for expanded application of cathodic treatment in combating rust and corrosion in water storage tanks and other structures.

***THE NEWS SECTION** was primarily incorporated in Corrosion to provide a record of the current activities of members of the Association, and to convey information of interest and value to members. All members are invited (in fact urged) to send releases, or letters, informing the editors of changes in positions, promotions, achievements, or other news items. All material should be forwarded to the Editor of Corrosion, 905 Southern Standard Building, 711 Main Street, Houston 2, Texas.*

The Challenge to the Corrosion Engineer

ONE OF THE highlights of the NACE 1947 Chicago conference was the address on the subject, "A Challenge to the Corrosion Engineer," by H. H. Anderson, Vice President of Shell Pipe Line Corporation, Houston, Texas. Directing it to all corrosion engineers but particularly to those working with cathodic protection, the speaker phrased the challenge in three parts:

Three Parts of Challenge Outlined

1) To harmonize apparent confusion amongst corrosion engineers by
   a) reducing techniques to common denominators, and
   b) by reconciling differences of opinion as to corrosion and protection mechanisms;
2) To collect, compile and disseminate available experience and cost data needed to prove that corrosion prevention is good economy; and
3) To more effectively sell management on the value of corrosion engineers' service through the force of the "economic motive" applied with the power of simple explanation.

As to the first problem, the speaker quoted the example given by Dr. Logan in Bureau of Mines Circular 450, on Page 260, of the widely divergent results in the tests for protective current requirements by the three accepted criteria—the null method, the pipe-to-soil potential method and the current-density method. He mentioned the paper presented April 10th describing the new continuous-polarity method,* and expressed hope that this might help to harmonize the others.

Further as to the first problem, the speaker quoted conflicting opinions written concerning the protective mechanism in cathodic protection. The shielding of the buried metal from the attack of soil moisture was attributed by one author to a film of hydrogen whereas another attributed it to an oxide film. Mr. Anderson proposed that the terminology of cathodic protection should be carefully standardized by the NACE as a step towards harmonizing such apparent conflicts of various test results and expressions of opinions.

Dearth of Concise Cost Data

As to the second problem, he spoke of the dearth of local experience and concise cost data concerning not only leaks, commodity losses and other damages but also the resultant repair and preventive jobs —the latter so necessary to prove the dollar pay-out of preventive measures. He attributed this dearth to the newness of some plants, although in many older plants he said

*"*The Determination of Pipe Protection by the Continuous Polarity Method,*" Wm. E. Huddleston, will be reproduced in the July edition of CORROSION.

there probably has been a failure to properly record past experience. As a means of assisting all engineers in this respect, Mr. Anderson proposed that the NACE should collect, compile and issue all available (and reliable) data of this type.

As to the third problem—selling the boss—he pointed out that the problem is not unique with corrosion engineers, and is a personal one. He indicated that those engineers who have no trouble selling the boss are hardly aware that a problem exists; however, those who have difficulty overlook that it is often due to personal shortcomings. It stems, he asserted, from a failure of engineers to recognize in hard-headed business that making money is really more important than advancing science—unless that science will pay dividends. It is aggravated, he said, by a lack of facility in oral and written self-expression which prevents engineers from presenting their proposals to the boss in such a manner that they can be readily understood.

To quote Mr. Anderson in this last respect: "Some printed corrosion articles are written in a clumsy or complicated manner that confuses the reader if not the writer, and I'll bet much of the stuff written for the boss is just as bad. That's why the boss isn't sold. If he has the patience to read it he probably can't understand it. Writing or talking in such fashion is an engineer's worst professional handicap. To those who have that habit, I strongly urge the purchase and reading of two books†, both of which to all of you will prove as fascinating as they are instructive."

Mr. Anderson closed his address by reading "Our Billion-Dollar Side-Show."‡ This is a short article prepared by him and aimed to present simply to top management the story of Cathodic Protection. It stressed the benefits to industry, to be derived from an understanding of its general principles by operating executives, who must sympathetically support their corrosion engineers who are endeavoring to apply it.

†*"Technical Writing,"* by T. A. Rickard, 3rd Ed., 1944, John Wiley & Sons, New York.

"The Art of Plain Talk," by Rudolph Flesch, 3rd Ed., 1946, Harper & Bros., New York.

‡Reproduced in full in this edition of CORROSION, starting on page 2 of the News Section.

Lead Industries Association Elects Officers

AT THE annual meeting of the Lead Industries Association on May 9 at the Waldorf-Astoria Hotel, New York, Robert Lindley Ziegfeld was elected Acting Secretary and Treasurer. K. C. Brownell, Executive Vice President of American Smelting and Refining Co., was elected Vice President, member of the Executive Committee and Board of Directors. D. N. Burruss, Jr., General Manager of Metals Refining Co., was elected to the Board of Directors. All other officers and directors were re-elected.

Corrosion Previews

Salt As a Medium of Corrosion of Telephone Cables

By A .G. ANDREWS, *Cable Testing Supervisor Michigan Bell Telephone Co., Detroit, Mich.*

IN AREAS served by grounded direct current electric railways, it is necessary to provide electrical drainage for underground cables, to protect them from anodic corrosion. It has been shown that such electrical drainage increases the current in the earth from the rails to the cables. The collection of current is not usually detrimental to the cables, but the action of this current upon salt (NaCl) in the earth may cause sodium hydroxide to be formed at the cables, resulting in corrosion from chemical attack. However, the solubility of sodium hydroxide provides a means of limiting such corrosive attacks by flushing the ducts with water to remove the alkali.

Deposits of various kinds are frequently found on cables and in manholes. Determination of the corrosive qualities of such deposits is not usually possible from inspection, and simple chemical tests are used.

Investigation of the alkaline content of telephone conduit adjacent to rail switches is being made in an effort to predetermine locations where cables are subject to corrosion and failure.

A. G. ANDREWS

The author is in charge of cable protection maintenance in the Cable Testing Bureau of the Michigan Bell Telephone Co. He was born in Cleveland, Ohio, Oct. 3, 1888, educated in Cleveland public schools and received a B.E.E. degree from the Ohio State University. After graduating, he joined the Michigan Bell Telephone Company and has since devoted his time to the investigation of corrosion problems and the application of corrective measures.

Mr. Andrews is a member of the Detroit Committee on Electrolysis, and served as its chairman during the years 1943 and 1944.

Statistical Analysis of Test Containers for Condensate Well Corrosion Studies

By V. V. KENDALL
National Tube Company, Pittsburgh, Pa.

THE HISTORY of the high-pressure gas corrosion problem in gas condensate wells is quite short. First discovered in the Opelika, Texas, field in 1942, it was at first considered a local phenomenon. Investigation, however, proved this type of corrosion widespread, and greatly effecting the economics of the entire gas industry.

Under way for well over a year, the study of condensate well corrosion by a special committee by the National Association of Corrosion Engineers, has standardized the types and sizes of specimens of various materials to be inserted in the flow strings of these wells to determine resistance to the special, highly corrosive conditions encountered in this type of production.

For testing materials, two types of specimens and containers were designed. The washer-type specimen consisted of 14-gauge mild steel plates, 1.5-inches wide x 4.4-inches long, with a square hole stamped in the center to fit closely on a ⅞-inch square steel bar. These specimens were placed at right angles to each other on the bar and separated from each other and from the bar by proper insulation. The container was ten feet long and contained 129 specimens. The cylinder-type specimen fitted snugly in the pipe container so that the inside wall of the specimen was on a line with the inside wall of the gas flow-line. These specimens were cylinders, two inches long, of seamless tubing with an inside diameter of 1.510 inches and were separated from each other and from the pipe wall by proper insulation. This container was six feet long and contained 30 specimens.

Before proceeding with the testing of the various materials, it was deemed advisable to determine the variability due to the type of test specimen and the number of replicates of each material that should be used. Therefore, for the first trial period of 90 days, the specimens tested in each container were all of the same steel.

A statistical analysis of the resultant data was made with the following conclusions:

1) The standard error for 124 specimens in the washer test was plus or minus 17 percent of the mean. Four specimens each of 32 materials can be tested with an expected error of 8.64 percent.

2) The corrosion rate decreases from the gas inlet to the gas outlet end of the washer container, the equation for which has been calculated.

3) The standard error for 30 specimens in the cylinder test was 3.95 percent of the mean. By using blank specimens in the No. 1 and No. 2 positions, thereby removing the turbulence effect at the inlet and in the gas flow due to the flange, two specimens each of 14 materials can be tested with an expected error of 2 percent.

4) There is no significant change in corrosion rate from one end of the cylinder container to the other.

Corrosion Abstracts

ATMOSPHERIC CORROSION

Protection of Lighting Fittings against Weathering and Corrosion. W. E. HARPER AND C. A. MORTON, GEC J, **14,** 111-120 (1946) Aug.

Nature of atmospheric corrosion, protection (choice of materials); design; finishing; maintenance. References to various non-ferrous metals and alloys.—BNF.

Corrosion Resistance of Magnesium and Certain of Its Alloys Under Various Accelerated Atmospheric Conditions. R. R. ROGERS, D. A. TETU, AND H. LIVINGSTONE. Electrochem. Soc., Preprint 90-125 (1946).

Investigation to determine the corrosion resistance of commercially pure magnesium and of the magnesium alloys AZ31X, AZ61X, and M-1, by the use of accelerated tests. The conditions represented in the tests were inland indoor atmosphere, inland outdoor atmospheric, and marine atmospheric. Experimental results indicate good resistance to corrosion under the third condition. It is pointed out that most metals should resist marine atmospheric conditions satisfactorily when properly protected with paint.—BLR.

BOILER CORROSION

Inhibition of Corrosion. Measures for Indirect Fuel Saving. W. F. GERRARD, Chem. Age, **55,** 525-30 (1946) Nov. 2.

It is suggested that corrosion may be more expensive than boiler scale with respect to its being the cause for replacement of damaged equipment. The mechanisms of corrosion and principal methods of preventing corrosion, such as protective coatings, de-aeration and elimination of corrosive impurities, colloidal preventives and sacrificial anodes, are discussed briefly.

A Study of the Corrosion of Copper Alloy Condenser Tubes. N. W. MITCHELL, Chase Brass & Copper Co., Paper, ASME, Tulsa (Oct. 7-9, 1946); Abstr. Pet. Proc. **1,** 176 (1946) Nov.

The principal primary causes of corrosion are reviewed, to point out that most copper alloys in refinery and natural gasoline plant service fail by stress-corrosion cracking, corrosion fatigue, and impingement corrosion. Visible results of corrosion are described. A table included in the abstract gives hitherto unpub-

lished data secured from extensive corrosion tests indicating comparative resistance to attack by sulfur and water of the following copper alloys: antimonial admiralty, admiralty, red brass, 20 percent and 30 percent cupro nickel, aluminum brass, Muntz metal, and copper.

Thermal De-Gassing of Boiler Feed-Water. J. TEYSSLER, Strojnicky Obzor, **26,** No. ½, 9-12+ (1946) illustrations; Engrs. Digest, **3,** 10, 513-516 (1946) Oct.

The principle of thermal de-gassing equipment and application to help prevent corrosion in boiler feedwater are described.—INCO.

Corrosion of Plant Equipment by Steam and Water.—II. R. C. ULMER, Power Plant Eng., **50,** No. 11, 90-2 (1946) Nov.

Peculiarities of corrosion affecting steam lines, feed pumps, heaters and economizers. Pure feedwaters cause more corrosion in feed lines than those containing dissolved solids. A chart is given of the relative change in pH value with change in temperature of pure water. Excessive velocities in feed pipes tend to aggravate corrosion. Feed pump failures are result of a combination of chemical and mechanical factors. Corrosive factors differ in open and closed type heaters. Leakage and galvanic action around economizer handhole caps need careful attention. The use of proper material and corrective water treatment are the best possible safeguards against corrosion.—CEC.

Corrosion in Vertical Turbine Pumps. T. E. LARSON, Power Plant Eng., **50,** No. 9, 80-81 + (1946) Sept.

Galvanic action, carbon dioxide reaction, effect of stray currents, water-line corrosion from concentration cells, and deposits of iron oxide and calcium carbonate on various deep-well pump parts, are the types of corrosion commonly met in vertical turbine pumps used in municipal and industrial water-pumping plants in Illinois. Charts show the effect of water quality on galvanic action, and general corrosion resulting from contact of mineralized water with steel or cast iron, and the history of pump replacements in seven wells used by a concern whose property is overrun by stray currents from operating machinery. Pump parts vulnerable to corrosive attack of carbon dioxide are listed; and protective coatings enumerated. Use of acid for removing deposits in pumps is explained. Schemes for meeting recession of water levels are also outlined.

CATHODIC PROTECTION

Protecting Oil Storage Tank Bottoms with Magnesium. J. R. JAMES AND R. L. FEATHERLY, Dow Chem. Co., Paper, AIME. Galveston, (Oct. 3-5, 1946); Abstr. Oil & Gas J. **45,** 22, 88-9 (1946) Oct. 5.

Cathodic protection of buried metal structures i.e., tank bottoms and pipelines, by employing magnesium anodes is explained and illustrated by the case history of such an installation on Republic Pipe Line Co.'s Corpus Christi 150,000 barrel oil storage tank farm, which increased the entire installation life expectancy by approximately four to eight years. (Previous life expectancy of one of its 55,000-barrel tanks was seven to eight years). Curves show tank-to-soil potentials before and after installation of anodes on a 20,000-barrel tank. Full details are given.

Corrosion of Underground Structures in Gas Plants. C. F. MAYERHERM, Gas World, **125,** 236-268 (1946); Chem. Abs., **40,** 7141-7142 (1946).

In a typical gas-works corrosion situation, after any existing stray current effects have been eliminated or minimized it should be possible to obtain substantial further reduction in corrosion trouble through operation of a suitable cathodic protection system.—INCO.

Some Experiences with the Protection of Bare Pipe Lines Using Zinc. F. A. BROWNIE, Gas Age, **98** 19-21 (1946) Nov. 28.

The use of zinc anodes for the protection of the pipe lines of the Canadian Western Natural Gas, Light, Heat, and Power Co., Ltd., and Northwestern Utilities, Ltd., is described. Costs are tabulated and effectiveness is discussed.—GPC.

Cathodic Protection. C. H. McRAVEN, Texas Pipe Line Co., Paper, Texas College of Arts & Industries. (Oct. 28, 1946), Corr. **2,** 320-9 (1946) Dec.

The theory of cathodic protection in preventing corrosion is discussed and some of the basic laws governing the flow of current in the networks encountered in its application are reviewed.

Magnesium Anodes for the Cathodic Protection of Underground Structures. H. A. ROBINSON, Corr. **2,** 199-218 (1946) Oct.

Gives details of research program. Outlines a program of experimental field work to determine how magnesium would perform as a sacrificial anode, and to evaluate what advantages it might offer for the practice of cathodic protection. Six percent aluminum-3 percent zinc magnesium anodes are recommended for certain electrical conditions. Laboratory and field results tend to approach each other as improvements indicated by the former are incorporated in the latter.—BLR.

Metal Rectifier Developments—Possible Applications of Titanium Dioxide. H. K. HENISCH, Electronic Eng. **18,** 313-314+ (1946) Oct.

Discusses desired improvements in dry plate rectifiers: operation at 100° C. without great loss of efficiency or life, and high-voltage, low-current rectifiers of small size. Outlines work which has been done on selenium and germanium rectifiers. Explains how blue modification of titanium dioxide can be produced and explains why this material should be suitable for rectifiers. Outlines problems which must be solved in order to produce titanium dioxide rectifiers.—BLR.

CHEMICAL CORROSION

Corrosion Resistant Metal-Covered Rolls. H. R. STROHECKER, Youngstown Weld. & Eng. Co., Paper before Tappi, Ann. Mtg. N.Y.C., (Feb., 1946); Paper Tr. J., **123,** 11, 54 (1946) Sept. 12.

A brief description is given of the method of manufacture of metal covered rolls and their application in the paper industry. Covers are of Monel, nickel, stainless steels, Inconel, or any other metal which can be satisfactorily welded, and is available in the form of rolled sheet or plate. They are homogeneous sheets of metal which will wear and resist corrosion. For applications where

pressures are high, such as calender-stacks, it has been found that the available corrosion resistant alloys are too soft to withstand high unit pressures. In such an application the cover is cold rolled or stretched so that it becomes loose and useless. Development work with age hardening cover materials is now under way and covered rolls which will have much greater surface hardness and be applicable to higher pressure installations are being developed. The first of these rolls covered with "K" Monel is giving excellent service in an ink mill. A Monel covered chemical flaker has been in continuous service for eight years. It replaces a cast iron roll which required refinishing every ninety days. —INCO.

Causes of the Serious Corrosion of Lead in an Intensive System sulphuric Acid Plant. K. WICKERT, Chem. Zeit., **64,** 411-413 (1940); Chem. Zentr., **112,** 1, 1734 (1941); J. Inst. of Met. & Metall. Abs., **13,** 296 (1946) Aug.

The extensive destruction of the lead was characterized by deeply corroded drop-form cavities. The lead so destroyed was of standard quality; the bismuth content was less than the permissible limit. The corrosion was found to be due to chlorine, the action of which was further intensified by the formation of nitrogen-oxychloride in the presence of nitric acid. Sulphur dioxide retarded the corrosion of the lead by chlorine and nitrogen-oxychloride. The chlorine came from the tap-water in the system.—INCO.

Corrosion Studies on Lead Alloys. K. WICKERT, Korros. und Metallschutz, **18,** 357-361 (1942); J. Inst. of Met. & Metall. Abs., **13,** 296 (1946) Aug.

A series of lead alloys was studied for employment in intensive-systems sulphuric acid plants. A method of test with "mixed acid" at 90° C. in a sealed tube gave results in agreement with service experience. Silver was the only alloy addition that improved the behavior of lead in this test. Silver and also nickel and copper are stated to improve alloyed leads by neutralizing the effects of deleterious constituents. Action of concentrate hydrochloric acid and of sulphuric acid at 90° C. on the same lead alloys is described, as well as electrochemical studies of protective film formation.—INCO.

Contribution on the Chemical Corrosion (by Lactic Acid) of Zinc Alloys. K. RUTTEWIT, Korros und Metallschutz, **18,** 11-12 365-368 (1942); J. Inst. of Met. & Metall. Abs., **13,** 297 (1946) Aug.

Tests of various zinc alloys in one lactic acid solution at room temperature revealed no composition that could be recommended as a substitute for the materials hitherto used for coinage, uniform decorations, etc. Only a few additions improved the corrosion behavior in lactic acid, viz., mercury, cadmium, and magnesium and their effects were only small. Alloys containing 10 percent aluminum and 0.1-0.5 percent silicon retained a bright surface in spite of a relatively large loss in weight.—INCO.

Corrosion of Zinc from the Viewpoint of the Battery Chemist. C. DROTSCHMANN, Korros und Metallschutz, **19,** 188-197 (1943); Chem. Abs., **40,** 6347 (1946).

The influence of impurities, surface condition, and thermal pretreat-

ment of the zinc sheets and that of variations in composition of the electrolyte and of the anode mixture upon the corrosion of dry cell cups is reviewed. Experiments are described confirming the well-known beneficial effect of amalgamation upon the corrosion resistance of the zinc.—INCO.

COATINGS

A New Method of Protecting Machines for Shipment or Storage. Mach., **53,** 2, 154-156 (1946) Oct.

A new method of protecting machinery or other objects for shipment or storage consists of an initial spraying operation which bridges large openings and empty spaces with long web-like filaments that completely enclose the part being packaged. Subsequently, spray applications of a new plastic, consisting of modified film-forming vinyl resins carried in volatile solvents, produce a durable, tough, flexible, moisture-impervious covering that withstands exposure to wind, rain, snow, and sunlight over long periods. This new plastic is known as "Cocoon." An aluminum top coating is also applied by spraying. For storage requirements involving extreme conditions, such as extended outdoor storage, the top coating usually applied is "Insul-Mastic," a Gilsonite-base material that is sprayed on and that forms a good bond with the Cocoon. This material, which has been used as a roofing material on freight cars for many years, has an indicated life expectancy of over fifty years, as shown by accelerated weathering tests.—INCO.

Protection of Steel Hulls against the Destructive Action of the Sea by Paint. G. DECHAUX, Peintures, Pigments, Vernis, **17,** 251-60 (1942); Chem. Abs., **40,** 6832-3 (1946).

Hull paints compounded from linseed oil, rosin, lead-oxide, and zinc-oxide are hardened at the anodes and softened at the cathodes by exposure to sea water. The cathode film is distinctly alkaline. Where the anodic film is plugged by iron oxide, it is very waterproof. A scheme covering 12 conditions of electrochemical corrosion is set up. The problem of an adequate hull paint should be solved by using suitable salt water-resistant binders, not by using inhibitor pigments. Asphalt and bituminous coatings, in conjunction with an antifouling coat, give excellent results; a copper-zinc coating sprayed on with the Schoop gun is good but blisters at pH 4. A three-coat combination of asphaltic primer, damar-china wood oil-iron oxide-zinc oxide anticorrosive coat, and antifouling coat, gave excellent results. Various tests for hull paints are given.

Corrosion Prevention. Metals Rev., **19,** 7, 16 (1946) July.

Using a portion of the Golden Gate Bridge as the proving ground, a demonstration conducted here revealed a war-developed means of attacking corrosion. The demonstration consisted in applying to the metal surface of the bridge, by means of a specially designed gun, a zinc coating of sufficient thickness to protect it against the corrosive effects of constant salt spray. Glasproz process is equally designed to coat with lead, tin, aluminum, brass, bronze, copper, manganese, Monel metal, silicon nickel, iron, and chromium, and with glass and plastics.—INCO.

Acid Proof Coatings for Water-Conditioning Installations. A. P. MAMET, Izvest. VTI, **15,** 3, 24-7 (1946); Chem. Abs. **40** 6721 (1946).

Of various coatings of acid proofing materials tested on parts of a water-treating installation perchlorovinyl varnish was very effective; rubber chloride was still more effective, but the supply is limited. Polychlorovinyl and its products were used successfully on surfaces which were not sharply curved. Where elasticity was not required a mixture of divinylacetylene polymers and Rubrax performed well. The latter alone was unsatisfactory. Ordinary enamel and automobile lacquer failed.

The Mutual Displacement of Metals from Vapors of Their Salts and the Application of These Processes to the Protection of Metals. N. A. IZGARYSHEV, Izvest. Akad. Nauk USSR, **6,** (Khim.), 673-681 (1941) (In Russian); J. Inst. of Met. & Metall. Abs., **13,** 355 (1946) Oct.

The process of the displacement of chromium and aluminum from vapors of their chlorides has been studied, and also the diffusion layers formed by these metals in iron and steel. The corrosion- and heat-resistance of parts protected by aluminum and chromium is demonstrated.—INCO.

A Study of Primers for Ferrous Metals in an Atmospheric Exposure. Am. Paint J. (Convention Daily), **31,** 34-35 (1946) Nov. 6.

Results of New England testing of a large number of primer formulations on cold-rolled steel panels and hot-rolled angle irons are presented in a table.—BLR.

The Formulation of Anticorrosive Compositions for Ship Bottoms and Underwater Service on Steel. II. F. F. DERBY AND J. C. HUDSON, Paper No. 18/1946 of the Corrosion Comm. (submitted by the Marine Corrosion Subcom.); J. Iron Steel Inst. (London), advance copy: 24 pp. (Aug., 1946); Chem. Abs. **40,** 6831-32 (1946).

A second series of raft tests by the Marine Corrosion Commission on anticorrosive paints for underwater use on ship bottoms has confirmed and enlarged earlier results. The paint recommended for general use comprises a pigment of two parts basic lead sulfate and one part each of white lead, Burntisland red, and barytes bound in a modified phenol-formaldehyde-litho-oil medium. Paints in a chlorinated rubber medium give good results, but present technical difficulties.

Antifouling Paints. ARTHUR E. BURNS, JR., Paint and Varnish Prod. Manager, **26,** 285+ (1946) Nov.

Reviews work on antifouling paints and theories of their action. Summarizes principles and conclusions established by Navy-sponsored antifouling paint research during the past ten years. 15 ref.—BLR.

Action of Pigments in Anticorrosive Paints. Paint, Oil & Chem. Review, **109,** 46 (1946) Oct.; Condensation of paper by H. Wagner, Korros. und Metallschutz, **20,** 221-224 (1944).

Author doubts validity of theories for corrosion protective action of zinc chromate based on assumption that chromate ions come into direct contact with the metal surface and react with it chemically. Advances

theory that beneficial influence of zinc chromate is the result of chemical reaction with the binding medium which leads to the formation of soaps and to more resistant films. —BLR.

CONSTRUCTION MATERIAL

Plastic Tubing. Gas Age **98**, 13-14 (1946) Dec. 26.

Plastic tubing as a substitute for steel pipe during the current shortage in making connections between the company's gas main and domestic meters has been found feasible by the San Diego Gas & Electric Co. Known as Tenite No. 11, the tubing is made of cellulose acetate butyrate, it will withstand pressures up to 550 psi, or more than 500 times the normal pressure found in domestic mains. The tubing is resistant to moisture, acids and alkalies and will not corrode. Plastic sleeve connections are employed to join the sections of tubing into longer runs.

Building Materials and Structures: Plumbing Manual. U.S. Nat. Bur. Stand. Report BMS66, Nov., 1940, 70 pp. Obtainable from Superintendent of Documents, Washington.

Includes recommendations with regard to copper, brass, lead and galvanized iron and steel tubes and pipes; brass or bronze pipe fittings; joints in copper tubing, joints between lead and other piping, wiped joints, etc.—BNF.

New Ceramic Combines Ceramic Materials and Powdered Metals. Parts I and II. HENRY H. HAUSNER, Cer. Ind., **47**, 87-88 (1946) Oct.; **47**, 90+ (1946) Nov.

By means of new process, such properties as magnetism, electrical conductivity, heat conductivity and hardness can be incorporated into ceramic products. Discusses potential applications and points out close relationship of powder metallurgical and ceramic processes. Describes experiments along the lines of mixing, compacting, and heat-treating to form homogeneous material; and combining the two types of materials in the forms of bonded materials. Preliminary experiments, the results of which are illustrated, indicate the feasibility of both types of processes. —BLR.

Carbon and Graphite for Corrosion Resistance. C. E. FORD, Nat'l Carbon Co., Corr. **2**, 219-33 (1946) Oct.

The process of manufacturing carbon and graphite is described briefly and their application as corrosion resistant structural materials for the process industries are discussed. Their use as ground anodes in cathodic protection, in heat transfer equipment for corrosive fluids, pipes, valves, and towers is described.

CORROSION TESTING

Accelerated Corrosion Testing of Protective and Decorative Coatings. R. R. ROGERS, Can. Chem. and Process Ind., **30**, 91-94 (1946) Oct.

Outlines factors controlling corrosion rates; describes and discusses the various types of corrosion testing equipment, and its applicability to different problems.—BLR.

Aspects of Grease Corrosion. H. A. MCCONVILLE, Gen. Elec. Co., Gen. Elec. Review **49**, 10, 30-31 (1946) Oct.

A discussion of effect of organic acids formed by oxidation of grease. In general, their presence inhibits

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rust, rather than otherwise. Acids of low molecular weight (acetic or butyric) if they are water-soluble, can be corrosive if present in sufficient quantities in presence of moisture. Higher molecular weight acids (palmitic, oleic and stearic) should not attack metal. Results of tests using copper and copper alloys are reported. Formation of copper soaps may not be undesirable and these may act as lubricants in gears, etc. The compounds formed are not crystalline but amorphous. A corrosion test for grease is described.—INCO.

Rusting Characteristics of Turbine Lubricating Oils. W. P. KUEBLER, Westinghouse Elec. Corp., Paper, ASME, Chattanooga, (April, 1946); Mech. Eng., **68,** 10, 889-893 (1946) Oct.

First public presentation of data on this by Western Electric. The history of the rusting problem and the development of tests are described in detail. Test panels from as early as 1937 are shown. Methods of Westinghouse as submitted in ASTM cooperative rusting tests are described as well as the work of the ASTM Committee on Turbine Oil (Sub-Committee XI. to Tech. Comm. D. of D-2).—INCO.

Inter- and Intracrystalline Corrosion and Their Causes. F. C. ALTHOF, Z. Metallkunde, **36,** 8, 177-186 (1944) Aug. (In German).

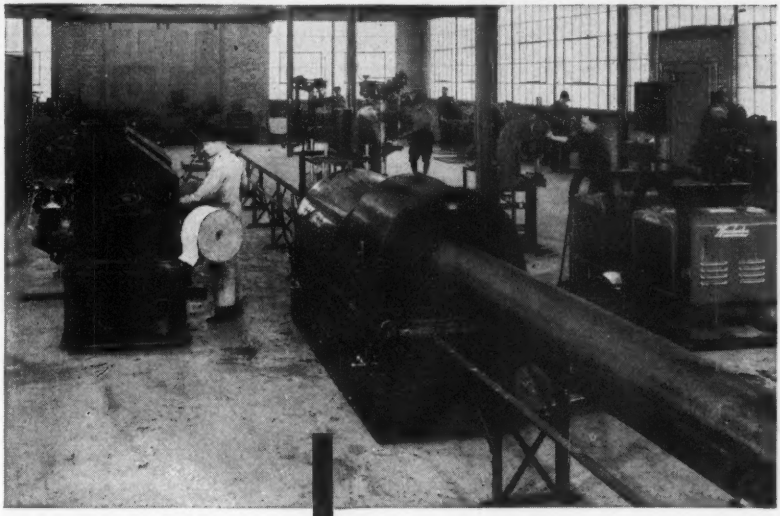
Results of tests carried on at the Ernst Heinkel A. G. since 1934, are reported with tables and micrographs. Brass was exposed in mercurial nitrate solution, ammonia atmosphere, artificial sea water and ammonia water. Course of cracks and nature and causes of inter- and intracrystalline corrosion are discussed. 25 references. Alloys Ms 55 through 86 are covered.—INCO.

FUNDAMENTALS

Physico-Chemical Study of the Decomposition of Some Solid Solutions of Aluminum. P. LACOMBE, Rev. Metallurgia, **41,** 6, 180-187; 7, 217-226; 8, 259-272 (1944), (In French); Chemie et Industrie, **55,** 3, 203-204 (1946); Chem. & Met. Eng., **53,** 7266+ (1946) July.

Electrochemical study of the decomposition of solid solutions of aluminum show that the rate of corrosion depends on its crystalline and electrochemical nature. Thermal decomposition of a solid aluminum-magnesium solution shows that the anomoly toward 280° F. heat cannot be attributed to a change of state corresponding to an equilibrium diagram. The absence of reversibility and disappearance of that anomoly leads to the hypothesis of an intermediate unstable precipitated phase incapable of existing above a temperature of 280° F. The mechanism of the decomposition of solid solutions can be summed up schematically by defining the different reaction stages as follows: unbalanced solid solution, balanced solid solution, intermediate phase oriented in relation to the solid solution, stable equilibrium phase more or less related to the multiple orientation with respect to the intermediate phase. —INCO.

Chemistry and Morophology of Films in Corrosion Studies with Zinc. W. FEITKNECHT AND R. PETERMANN, Korros. und Metallschutz, **19,** 7, 181-188 (1943); J. Inst. of Met. & Metall. Abs., **13,** 297 (1946) Aug.



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Controlling Factors in the Corrosion Process. N. D. TOMASHOV, C. r. Acad. Sci. URSS, **52,** 785-8 (1946).

It is shown how, given the polarization curves for the corrosion process, to determine the ratios of the resistances of different corrosion stages and thus obtain a quantitative characteristic of the control of the corrosion process under consideration.

Oxide Films Formed on Alloys at Moderate Temperatures. EARL A. GULBRANSEN, R. T. PHELPS AND J. W. HICKMAN, Ind. Eng. Chem. (Anal. Ed.), **18,** 640-652 (1946) Oct.

Supplementing previous papers, electron microscope and electron diffraction data are presented concerning the structure of electro-chemically and chemically stripped films from a series of 16 alloys consisting principally of iron, cobalt, nickel, and chromium. Both reflection and transmission methods of electron diffraction were used. 17 ref.—BLR.

GAS AND CONDENSATE WELL CORROSION

Sodium Chromate Used in Permian Basin Drilling to Combat Salt-Water Corrosion. G. WEBER, Oil & Gas J. **45,** 31, 103 (1946) Dec. 7.

Although laboratory immersion tests show that a sodium chromate concentration of 1000 ppm reduces corrosion of steel samples in salt-water muds by 94 percent, in practice the proportion used in drilling muds ranges from 1800 to 3000 ppm, and averages 2000 ppm. Most drillers mix 50-100 pounds of chemical to about 50 gallons of water in a common oil drum or chemical mix tank. It is added slowly in the amount calculated to give the desired proportion, at the rate of 50 gallons per hour into the flow line, either before or after the shale shaker. At the average strength of 2000 ppm, sodium chromate costs 6 cents per foot drilled on most Permian basin wells. Sodium dichromate may also be used in the field since it is easily reduced to sodium chromate by mixing with caustic in the proportion of 25 pounds of caustic to 100 pounds of sodium dichromate. The adverse supply situation of sodium chromate is discussed briefly.

Corrosion and Preventive Methods in the Katy Field. R. C. BUCHAN, Oil Weekly, **123,** 25+ (1946) Nov. 18.

The author describes briefly the Katy gas-condensate field, the producing and cycling equipment used, and its operation. The effects of acidic-water corrosion are illustrated and discussed. The use of plastic-coated pipe and the use of soda-ash as a neutralizing agent are described as being practical means of reducing

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corrosion losses in the Katy field. The need for continued research and for field testing of alloys is pointed out. Instead of waiting for a complete understanding of such problems, it is advocated that full-scale field tests be initiated as soon as corrosion is found in new fields. The arrangement of subsurface equipment to facilitate corrosion control is discussed briefly. The importance of keeping equipment in safe working condition is emphasized. An API paper.—GPC.

Use of Formaldehyde to Inhibit Corrosion. J. A. CLAY, JR., Service Eng. Inc., Pet. Eng. **18,** 2, 111-12+ (1946) Nov.

When using formaldehyde as a corrosion inhibitor, several different types of injection systems have been tried. The most successful and simple systems yet devised may be separated into 2 classes; 1) those for high pressure wells, and 2) those for low pressure wells. For the first class a lubricator of some type has been found satisfactory. Two examples are shown and described. Also described is an economical type for use on wells with a casinghead pressure of less than 50 psi. The system consists of a container drum, a barrel pump or grease pump, and enough 0.5-inch pipe and connections to hook it up to the casinghead opening. Since inhibiting efficiency decreases with temperature, formaldehyde, is unsuitable in wells exhibiting a high bottom hole temperature. When properly used it usually is 80 percent effective against corrosion due to hydrogen sulfide saturated brines or acids at low temperatures. Best results are obtained if the following conditions are observed: 1) Formaldehyde must be injected every day to maintain the thin protective film. The batch treatment is recommended; 2) Wells must be produced daily; 3) Injection system should be closed to exclude air; 4) Formaldehyde must reach the bottom of the well; 5) When treating a low pressure well the casinghead should be closed in; 6) Periodic checks of the hydrogen sulfide content of the produced water, and of the efficiency of any insulation material used, should be made; 7) When treating a well with old equipment in it, first remove the sulfide scales. The amount of formaldehyde to use varies with: 1) amount of surface area of equipment to be protected; 2) dilution effect of the produced fluids, and 3) severity of the corrosion.

Laboratory Studies for Determination of Organic Acids as Related to Internal Corrosion of High Pressure Condensate Wells. E. C. GRECO AND H. T. GRIFFIN, Corr., **2,** 138-151; discussion, p. 151-152 (1946) Sept.

Gives details of electrometric titration analyses of samples of waters from these wells, to determine the amounts of organic acids present, believed to be responsible for much corrosion.—BLR.

Corrosion Problems in the Petroleum Production and Pipe Line Industry. WALTER F. ROGERS, Corr., **2,** 59-63 (1946) Mar.

Outlines the various research investigations which have been and are being carried on in recent years on corrosion of pipe lines, refinery equipment and oil-well pipe and equipment. Latter problem is being investigated by a group at Battelle Memorial Institute.—BLR.

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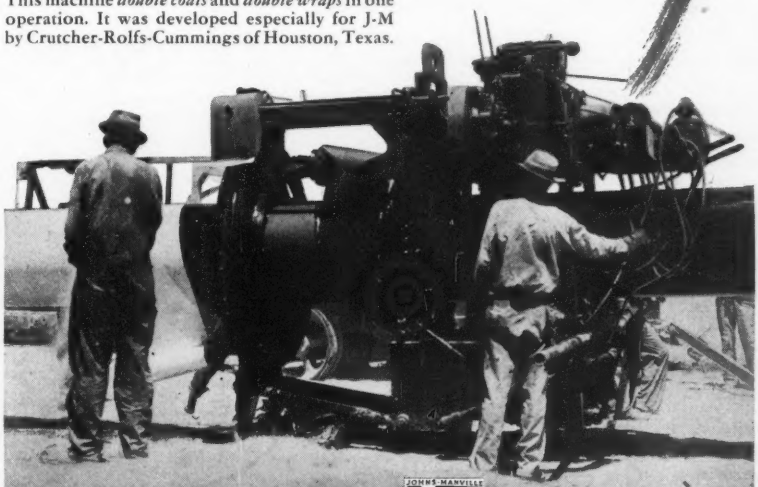

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GENERAL CORROSION

Corrodibility of Some Common Metals and Alloys. Metal Prog., **50,** 884-B (1946) Nov.

Corrodibility is tabulated for 56 metals and alloys; with respect to water, seashore and industrial atmospheres, various acids and alkalies, salt solutions sulphite liquor, dye liquor, and sweet and sour refinery crudes. Also gives maximum safe temperatures with respect to oxidation resistance to three types of gases.—BLR.

Control of Galvanic Corrosion of Iron. C. K. DONOHO AND J. T. MACKENZIE, Corr., **2,** 20-24 (1946) Mar.

Explains causes of galvanic corrosion in iron and steel structure and in fusion welds. Shows how polarity of welds may be determined by the "agar test" and how iron may be protected against corrosion by alloying with nickel or copper. —BLR.

Some Experiments on the Effect of an Electrostatic Field on the Corrosion of Steel. S. EISNER, Rev. Universelle Mines, **2,** 9, 23-25 (1946) Chem. Abs., **40,** 6399 (1946).

In a study of rust formation on rustless steels it was observed that after a rusty spot was produced (by a 3 sodium-chloride drop) a passive area appeared around the spot; this seems to indicate that an electric field forms between the rust spot, acting as anode, and the area in its immediate surrounding, acting as cathode. With an artificial anode the same phenomenon occurs. The variable passivity of steel and iron and the cathodic, protection can be explained in this way.—INCO.

The Use of Dehydration in Combating Internal Corrosion in Products Pipe Line Systems. H. K. PHIPPS, Socony-Vacuum Oil Co., Oil & Gas J. **45,** 29, 67+ (1946) Nov. 23.

A brief review of the problem of internal corrosion in products lines and the use of scrapers in alleviating it is given. A detailed description of the Socony-Vacuum dehydration process is included. Based on contacting the water-contaminated products with activated alumina, this procedure was first adopted in 1936 and Socony is the only company using this process extensively. Diagrams, photographs and operating data of a typical unit are included. It is pointed out that dehydration differs from all other methods in that it completely eliminates the source of the trouble rather than attempting to neutralize or mitigate its effects.

Corrosion and Chemical Behavior of Zinc and Zinc Alloys. K. BAYER, Korros. und Metallschutz, **18,** 362-365 (1942) J. Inst. of Met. & Metall. Abs., **13,** 296-297 (1946) Aug.

The behavior of zinc and zinc alloys when subject to atmospheric corrosion or attack by natural waters, at both normal and elevated temperatures, is surveyed and the results of the more important German investigations in this field are briefly cited.—INCO.

Corrosion of Castings. Foundry Tr. J., **79,** 1567, 441 (1946) Aug. 29.

Brief editorial, commenting on various examples of galvanic corrosion, calling on engineering shops to publish electrical potential of wrought materials, mentioning the possibility of altering electrical po-

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Red Lead has earned its place as the "standard" metal-protective paint. One reason is its ability to react with the vehicle and produce unique lead "soaps."

These "soap" formations grow to form a tough, impervious, intermeshing matrix within the paint film (see photomicrographs). The "soaps" help Red Lead inhibit rust three ways.

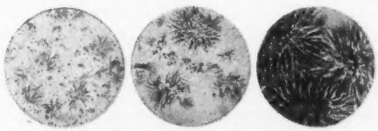
1. Toughen Paint Film. Radiating from central cores the "soap" formations develop rod-like projections. These form a dense intermeshing structure that *mechanically* reinforces and toughens the paint film.

2. Make Film Water-Resistant. The thick, impervious matrix of lead "soap" fibres helps restrict the passage of moisture through the paint film. And metal cannot rust without the presence of moisture.

3. Keep Film Flexible. The "soap" formations allow movement all along their soft, intertwining projections. This flexibility helps prevent the ruptures to which a hard, unyielding paint film is subject. Thus the lead "soaps" aid in maintaining the continuity of the paint film.

Lead "soaps" form primarily in the dry paint film as it ages and the vehicle decomposes. Red Lead's ability to slowly combine with the decomposition products actually enhances the life of the film. Red Lead's slow rate of reaction means the film age-hardens at a slower rate. It thus retains a high degree of flexibility, a great factor in its lasting adhesion.

Remember, too, Red Lead is compatible with practically all vehicles commonly used in metal protective paints, including many of the fast-drying resin types.



The photomicrographs above show how Red Lead "soaps" progressively spread out as they grow.

Specify RED LEAD for ALL Metal Protective Paints

The rust-resistant properties of Red Lead are so pronounced that it improves *any* metal protective paint. So, no matter what price you pay, you'll get a better paint if it contains Red Lead.

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tential of cast alloys through heat treatment, and pointing out that the cast iron industry has not made as much progress in corrosion research as steel. Corrosion of Monel sinks at junction with copper attachments is mentioned, as well as the fact that high silicon, high nickel irons are valuable as corrosion resistant materials, although "few would consider them suitable for applications other than their established uses, the chemical industry."—INCO.

Relative Corrodibility of Metals and Alloys. R. S. BURPO, JR., Mat. Meth. **24,** 1501 (1946) Dec.

The common metals and their alloys are listed in their order of electrochemical activity with brief remarks on their corrosive behavior in the case two different metals or alloys are in contact under moist conditions.

INHIBITORS

Inhibitor Effect in Pickling. K. WICKERT, Korros. und Metallschutz, **19,** 297-305 (1943) Chem. Abs., **40,** 6378-6379 (1946).

An inhibitor of unspecified composition, termed Vogel's inhibitor, was used. Equations were derived for a coefficient of inhibition, denoting the decrease in solubility of both metal and oxide as a consequence of inhibitor addition, and a coefficient of pickling efficiency which is directly proportional to the oxide solubility and indirectly to the metal solubility, both per unit of time. It was concluded that simultaneous exposures of metal and oxide are necessary for the evaluation of an inhibitor.—INCO.

Acide Cleaning of Boilers and Auxiliary Equipment. S. T. POWELL, Trans., ASME, **1946,** 905-917, Nov.

Acid-cleaning of equipment has been demonstrated over a long period as a useful and economical means for removing encrustations from boilers and many other types of power-plant equipment. This paper explains the use of various cleaning reagents and inhibitors, the procedure which should be followed, and the precautions to be taken to safeguard both personnel and equipment from the hazards inherent in the process.—GPC.

Corrosion of Tin Containers. F. JACOBSEN, O. A. RONOLD, AND K. STOKKE, Tids. Hermetikind., **31,** 47-50 (1945); Chem. Abs., **40,** 7141 (1946).

The corrosion of tin cans is principally dependent upon the amount of trimethylamine oxide in the canned products. Graphs show relation between dissolved tin per 100 g. of canned herring flesh to which were added ammonia, methylamine dimethylamine, trimethylamine, trimethylamine oxide, and sodium acetate, respectively, and storage time of canned products in months.—INCO.

INSPECTION

Detection of Pores in Paint Coatings by Electrical Means. Testing Lacquered Cans. Paint, Oil & Chem. Rev., **109,** 46-47 (1946) Oct. Condensation of paper by G. Schikorr, Korros. und Metallschutz, **20,** 43-51 (1944).

Describes experimental procedures used and compares results of laboratory and service tests.—BLR.

CATHODIC PROTECTION NEEDED?

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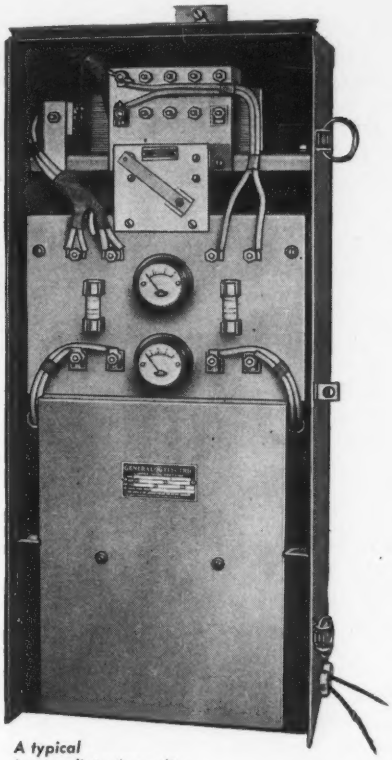

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GENERAL ELECTRIC

METAL FAILURE

The Stress Rupture and Creep Properties of Heat Resistant Gas Turbine Alloys. NICKOLAS J. GRANT, ASM Preprint 2, 46 pp. (1946).

Large number of rupture and creep tests at 1500° to 1800° F. and at stresses from 7000 to 15,000 psi. in rupture were made on a series of vitallium-base (cobalt-chromium-molybdenum) and nickel-chromium-cobalt-iron-base alloys. Variables studied were effects of increasing amounts of carbon and nitrogen and the hot strength and ductility of these alloys; the role of heat treatment and aging; the relationship of the stress to the rupture time and to the minimum creep rate measured in both rupture and creep tests. An important relationship was shown to exist between time at temperature and the resultant ductility at fracture. Results given.—BLR.

Aluminum-Magnesium-Silicon Alloys. The influence of the Silicon Content, and of the Corrective Elements Manganese, Chromium, and Titanium on the Tensile Properties and the Corrosion Resistance. C. PANSERI AND M. MONTICELLI, Allumino, **14,** 51-70 (1945); Chem. Abs., **40,** 22, 7129 (1946).

The mechanical properties and the resistance to the corrosion of the 2 percent silicon alloys are better than those of alloys containing less or more silicon. Titanium does not show any influence; manganese and chromium increase the mechanical resistance slightly; the addition of 0.25 percent chromium has the same influence as 0.7 percent manganese. After artificial aging, alloys with 0.3 percent manganese are the best. On heating at 530° and quenching in water at 0°, aging is complete after five days at room temperature, or after 12 hours at 160°. Chromium and managanese show hardening action, but are without influence on the aging. The addition of 0.7 percent manganese increases by 30° the temperature or recrystallization, and 0.2 percent chromium decreases this temperature by 20°. By increasing the silicon content, the corrodibility is increased.

The Constitution Diagram of Nitrogen-Containing Chromium-nickel Steels. H. KRANIER, AND M. NOWAK-LEOVILLE, VDE, Comm. on Materials, Report 588; Archiv Eisenhuttenwessen, **15,** 11, 507-513 (1942).

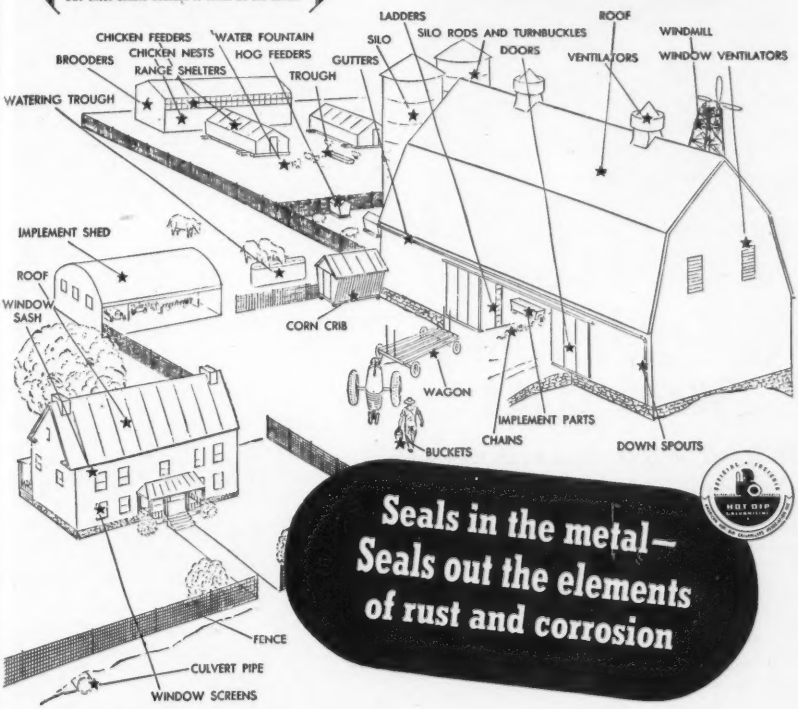
Thirty-nine low carbon steels with 10-30 percent Chromium, 3-30 percent nickel and 0.04-0.49 percent nitrogen were melted and studied for microstructure, magnetic saturation, hardness, and notched-bar impact in the quenched state as well as after anneals at 650° and 800° C. The results are summed up in diagrams showing the distribution of the phases at 1200, 800, 650 and 20° C. In chromium-nickel-nitrogen steels, when compared with straight chromium-nickel steels, new phases do not occur. The ranges of stability of the individual phases undergo changes and it is especially the range of stability of the phase which is widened toward lower nickel contents. The occurrence of the brittle sigma phase is found to be little affected by the addition of nitrogen. Photomicrographs, and 9 references are given. —INCO.

Effect of Alloying Constituents in Light Metals. S. A. J. SAGE, Mech. World and Eng. Rec., **119,** 362 (1946)

DIPPED IN MOLTEN ZINC

For the utmost in Rust Prevention

The metal parts of farm machinery, equipment, structures and installations are constantly exposed to the elements that are the cause of rust and corrosion. Hot-Dip Galvanizing definitely *seals out* these causes because it *seals in* the metal.



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Mar. 29. Corr. and Mat. Prot., **3,** 6, 25 (1946) June-July.

Discusses the effects of copper, silicon, iron, magnesium, nickel, manganese, zinc, bismuth, tin antimony, titanium, and cerium on the properties of aluminum. Magnesium, manganese or zinc additions to aluminum retard corrosion.—INCO.

Corrosion - Resistance After Cold and Hot-Age-Hardening of Aluminum - Copper - Magnesium Alloy Sheets with Different Clad Coatings. W. BUNGARDT, Metallwirts, **23,** 221-227 (1944); Brit. Abs., **BI,** 73 (1946) Feb.

Pure aluminum as a coating for duralumin-type alloys has the disadvantage of favoring diffusion of copper, while coatings of aluminum-magnesium-silicon-manganese alloys are subject to intercrystalline corrosion. Corrosion tests in stirred aqueous sodium chloride plus hydrogen peroxide were carried out on 12 samples of duralumin from different suppliers, coated with aluminum, aluminum-manganese, and aluminum-magnesium-silicon-manganese alloys. Specimens were solution-treated and then aged at both room and elevated temperature. The aluminum coatings gave the poorest protection, while the alloy coatings were of approximately equal value. The tendency of aluminum-magnesium-silicon-manganese alloys to intercrystalline corrosion had little practical effect on the resistance of the coated sheet.

ASTM Specifications for Steel Piping Materials. ASTM Committee A-1 on Steel—ASTM Philadelphia, (1946) Dec., 296 pp.

Specifications are given on pipe, tubes, castings, forgings, and boltings.

Engineering Properties of "A" and "L" Nickel. Met. Prog., **50,** 835 (1946) Nov.

Gives magnetic properties, physical constants, short-time high temperature tensile properties, endurance limit and apparent corrosion fatigue limits in tabular form and charts average tensile properties and hardness.—BLR.

Grain Boundary Penetrations by Liquid Metals. II.—Attack of Platinum Alloy Sparking Plugs by Molten Lead. P. J. E. FORSYTH AND W. R. SMITH, Metallurgia, **34,** 245-246 (1946) Sept.

Attack by lead arising from use of leaded fuels. Part I of this series (ibid., 34, 186-188 (1946) Aug., dealt with service failures due to the contact of molten metals with stressed parts.—BNF.

The Crystal Structure at Room Temperature of Eight Forged Heat-Resisting Alloys. J. H. KITTEL, NACE Tech. Note 1102 (1946) July.

Crystal structures of eight forged alloys S 816, S 590, Gamma Columbium, Hastelloy B, 16-25-6, 19-9 DL, Nimonic 80, and N 155 (low carbon) —were determined by X-ray diffraction methods to measure their suitability for high temperature use in gas turbines and jet propulsion engines. The predominant phase in each alloy was found to be a solid solution of the chief alloying elements. The crystal structure of the solid solution is the face-centered cubic type. Alloys S 816, S 590, and Gamma Columbium, which contained the largest percentages of columbium, were found to show diffraction lines from a second phase that is believed to be columbium carbide.—AER.

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Stress Corrosion of Austenitic Cast Irons. JOHN B. URBAN, JOHN W. BOLTON AND AUSTEN J. SMITH, Foundry, **74,** 88-90+ (1946) Nov.

Samples of austenitic cast iron were immersed in 50 percent caustic at 280° F. while being subjected to long period tensile loading. Results are shown graphically and in tables. Studies show that for the corrosive action and temperature considered there is a relatively high limiting stress below which the effects of stress-corrosion on austenitic irons are either negligible or nonexistent. —BLR.

Quantitative Evaluation of Intergranular Corrosion of 18-8 Titanium. FREEMAN J. PHILLIPS, ASM, Preprint 6, 16 pp. (1946).

Survey made of the detection, cause and methods of elimination of intergranular corrosion in 18-8. Quantitative method for predicting intergranular corrosion of 18-8 titanium developed for a given set of conditions. In deriving this method, an explanation was found for the corrosion of 18-8 titanium in which the titanium content exceeded the stoichiometric ratio of four times the carbon content. Method is based on microstructure and chemical composition and is thought to be applicable to other grades of stainless steels. —BLR.

Can Compression Stress Cause Fatigue Failure? JOHN C. STRAUB, Am. Mach., **90,** 120 (1946) Oct. 24.

Proposes modification of the statement that all fatigue failures are a result of tension stresses, showing actual failure may be caused by compression. Discusses stresses in simple bending.—BLR.

Electrochemical Behavior of Stainless Steels. IV.—Electrode Potentials of Stainless Steels and Their Components in Ferric Chloride Solutions. V. P. BATRAKOV AND G. V. AKIMOV, Comptes rendu (Doklady) de l'Acad. des Sci. de URSS., New Ser. **46,** No. 5, 191-192 (1945). Corr. & Mat. Prot. **3,** No. 1, 27 (1946) Jan.

Investigation of the electrode potentials of typical stainless steels in ferric solutions of different concentrations.

Abbreviations at end of abstracts indicate contributors cooperating in conjunction with the American Coordinating Committee on Corrosion, and the National Association of Corrosion Engineers to reproduce all abstracts pertaining to corrosion under one cover, in the NACE journal, Corrosion, and are as follows:

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